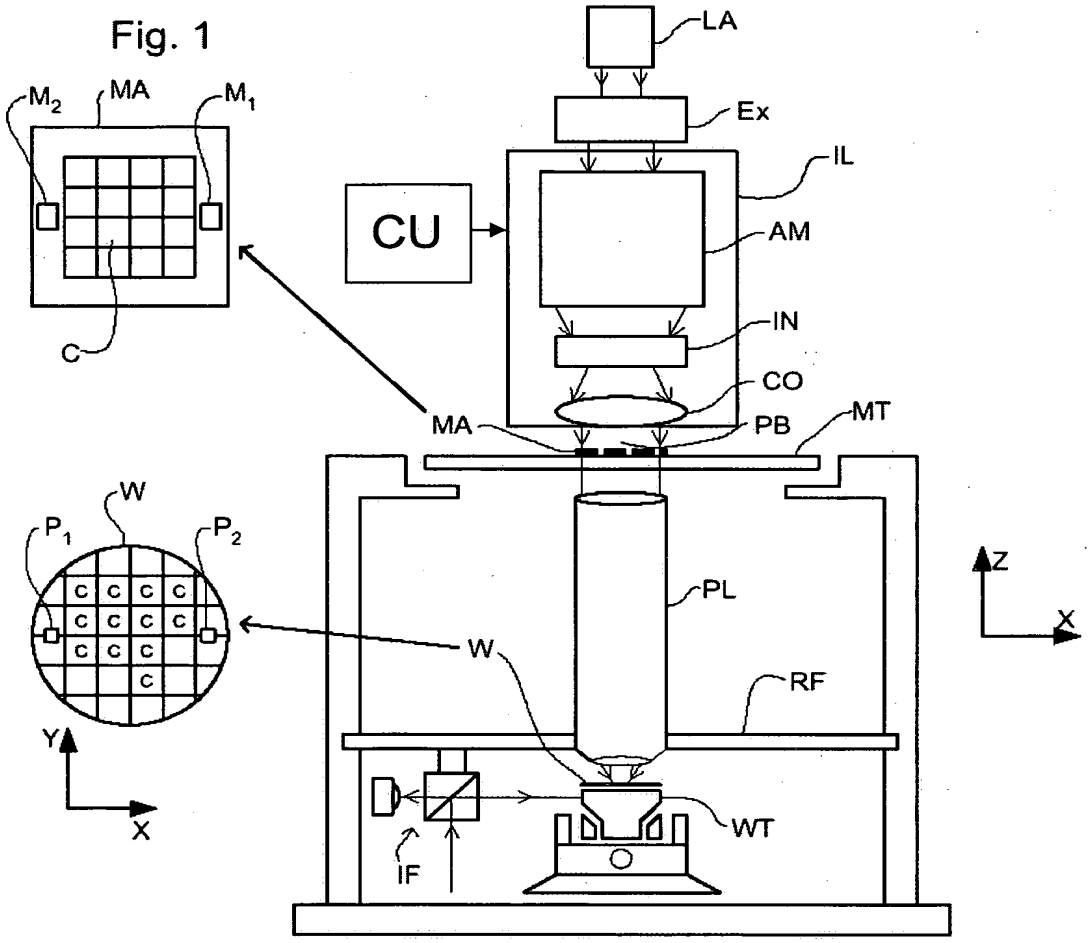
Fig. 1



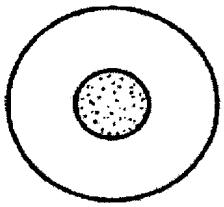


FIG. 2

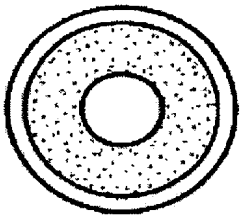


FIG. 3

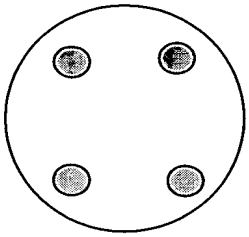


FIG. 4

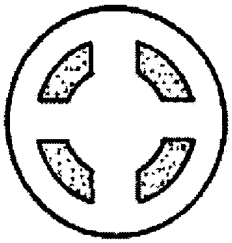


FIG. 5

FIG. 6

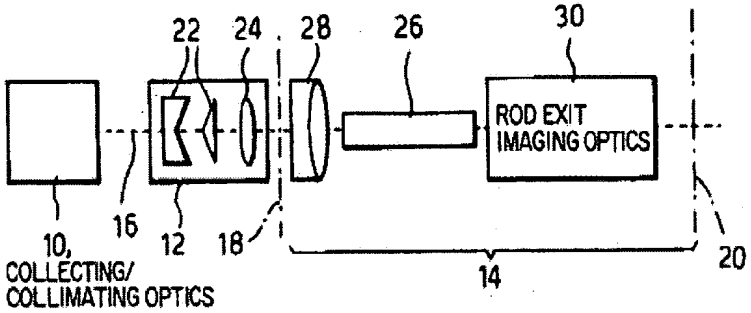


FIG. 7

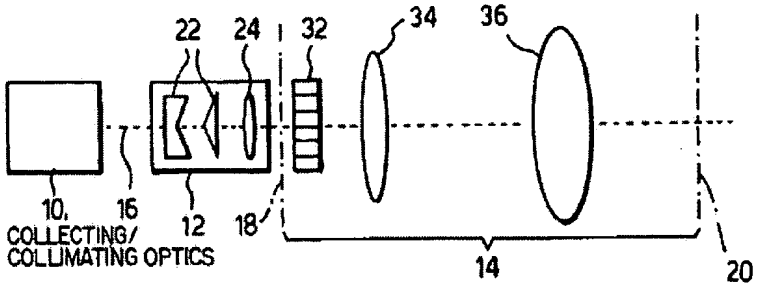


FIG. 8

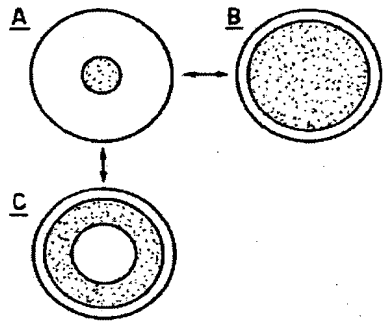
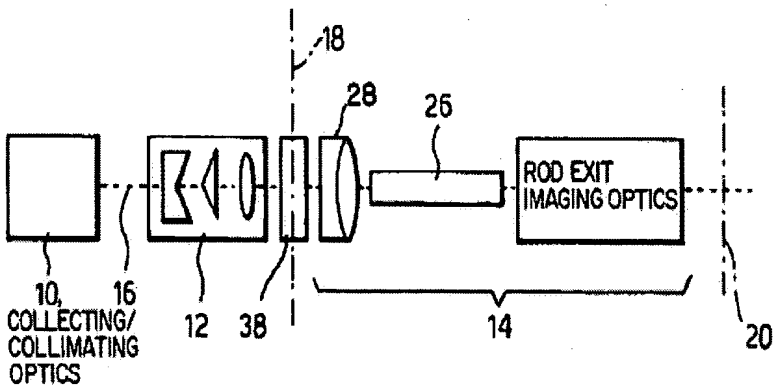

A
B
C

FIG. 9


18
28
26
ROD EXIT
IMAGING OPTICS
10,
COLLECTING/
COLLIMATING
OPTICS
16
12
38
14
20

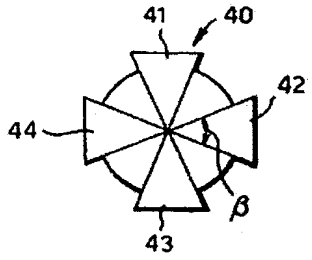


FIG. 10a

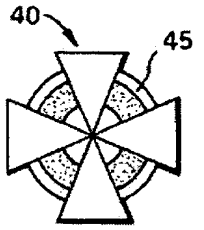


FIG. 10b

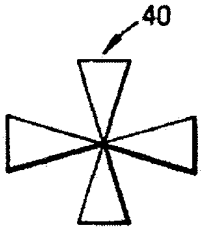


FIG. 11

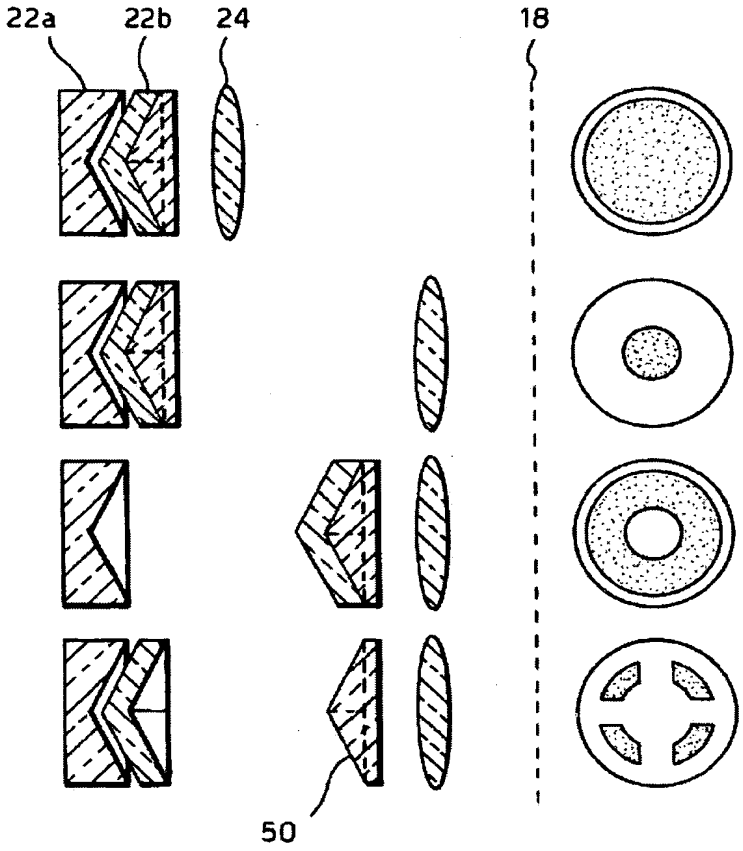


FIG. 12

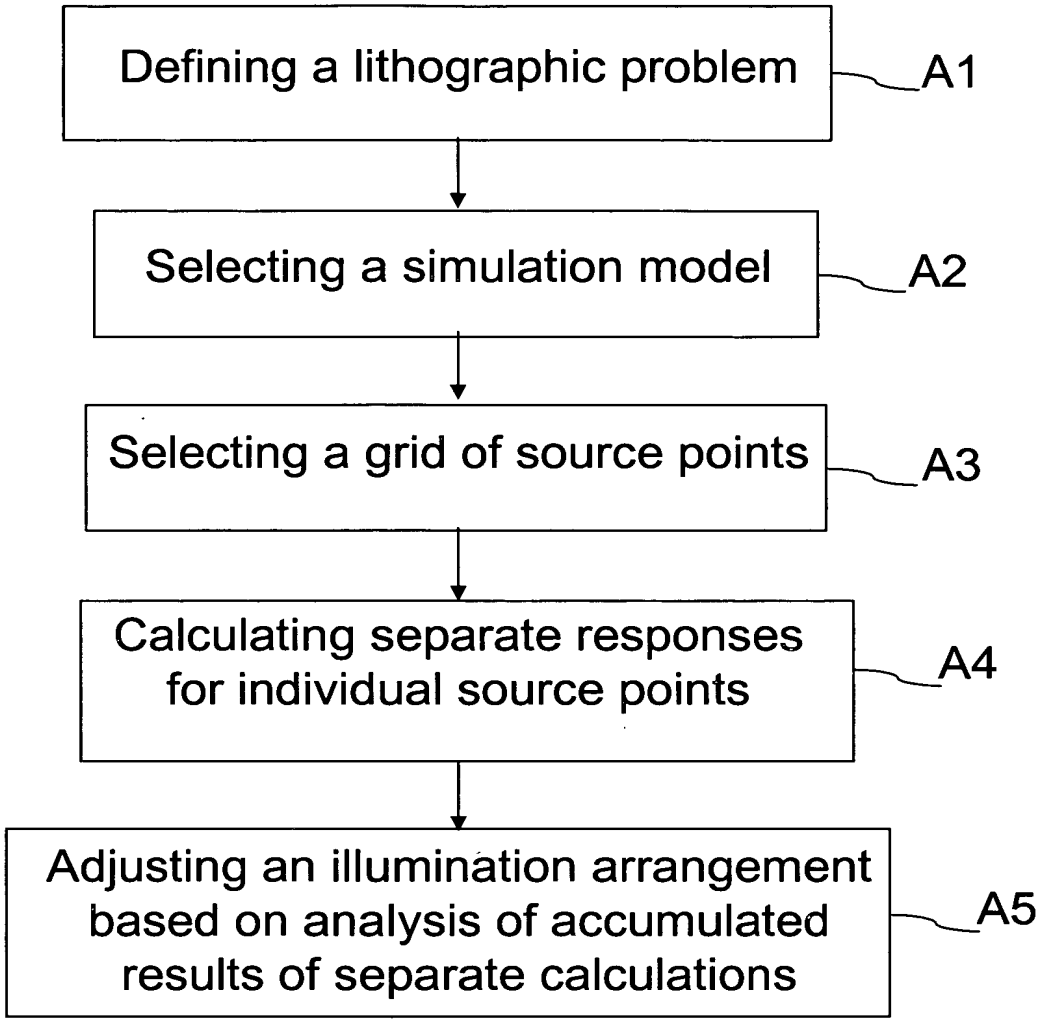

Defining a lithographic problem
A1
Selecting a simulation model
A2
Selecting a grid of source points
A3
Calculating separate responses for individual source points
A4
Adjusting an illumination arrangement based on analysis of accumulated results of separate calculations
A5

FIG. 13

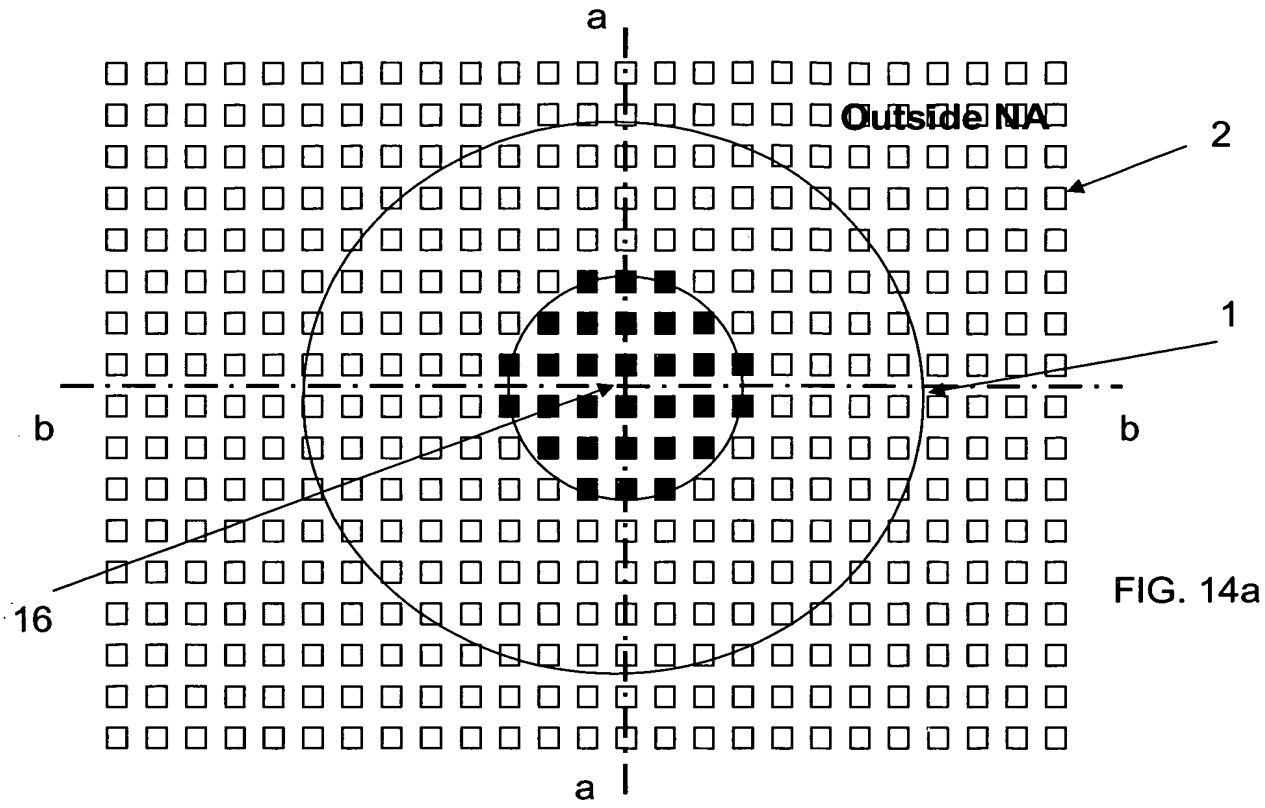


FIG. 14a

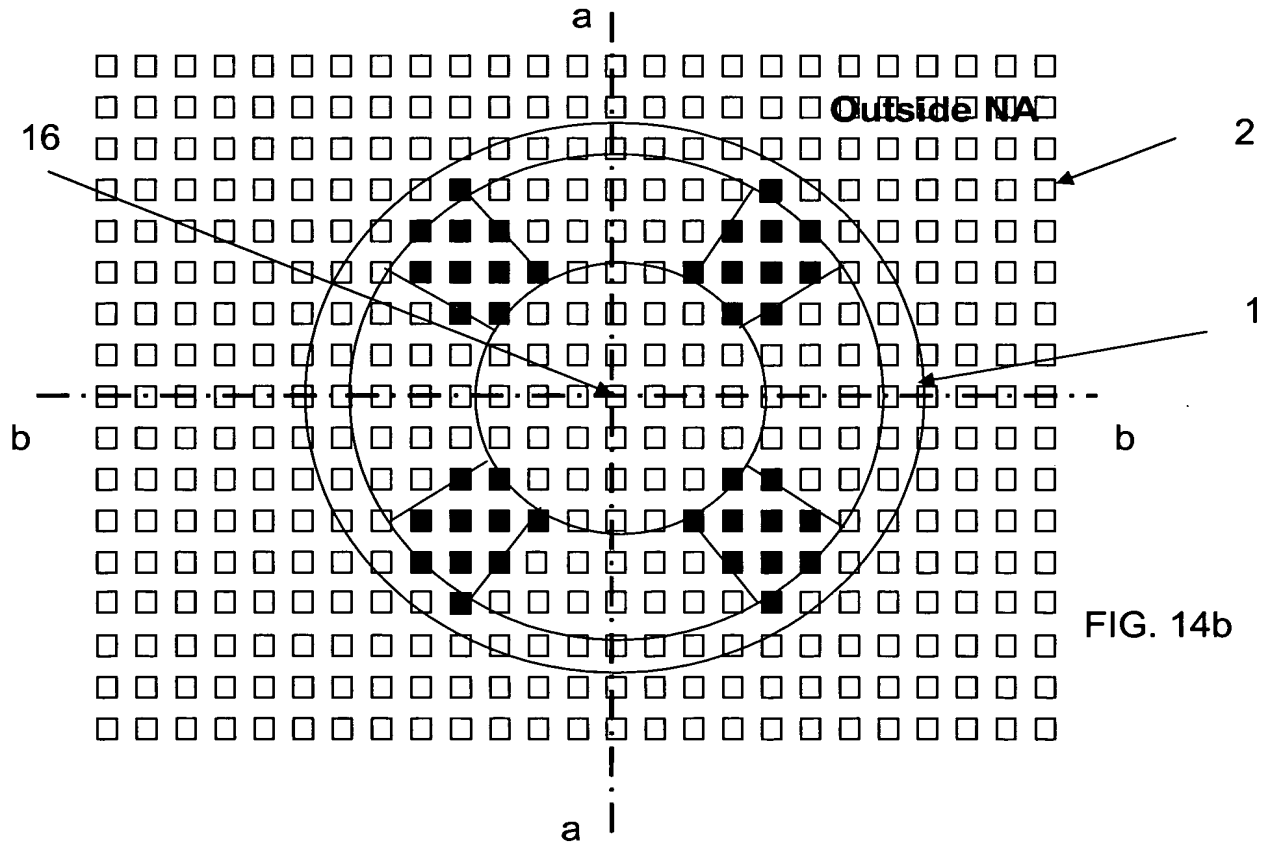


FIG. 14b

65nm CPL isolated lines, 193nm
0.85NA, scalar aerial image simulations
0.2μm defocus

high DOF expected with appropriate Quasar

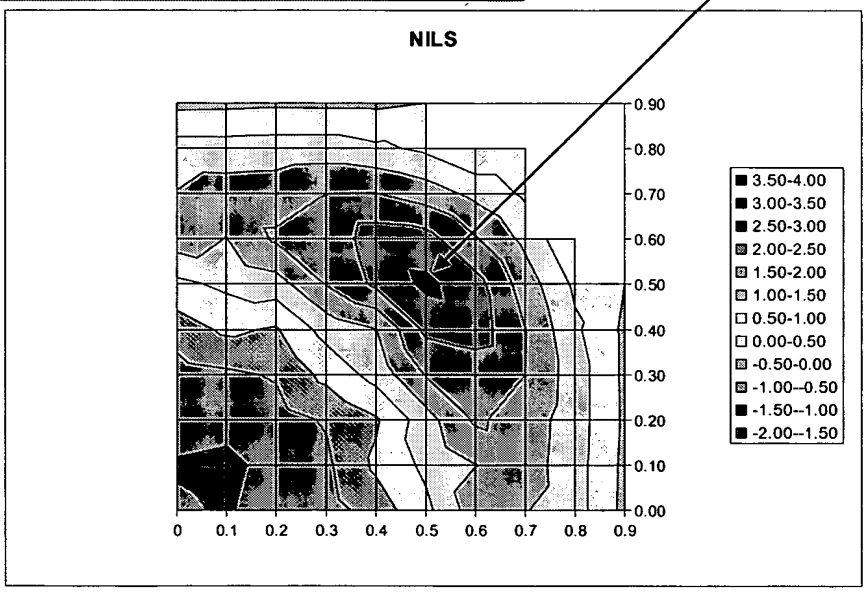


FIG. 15

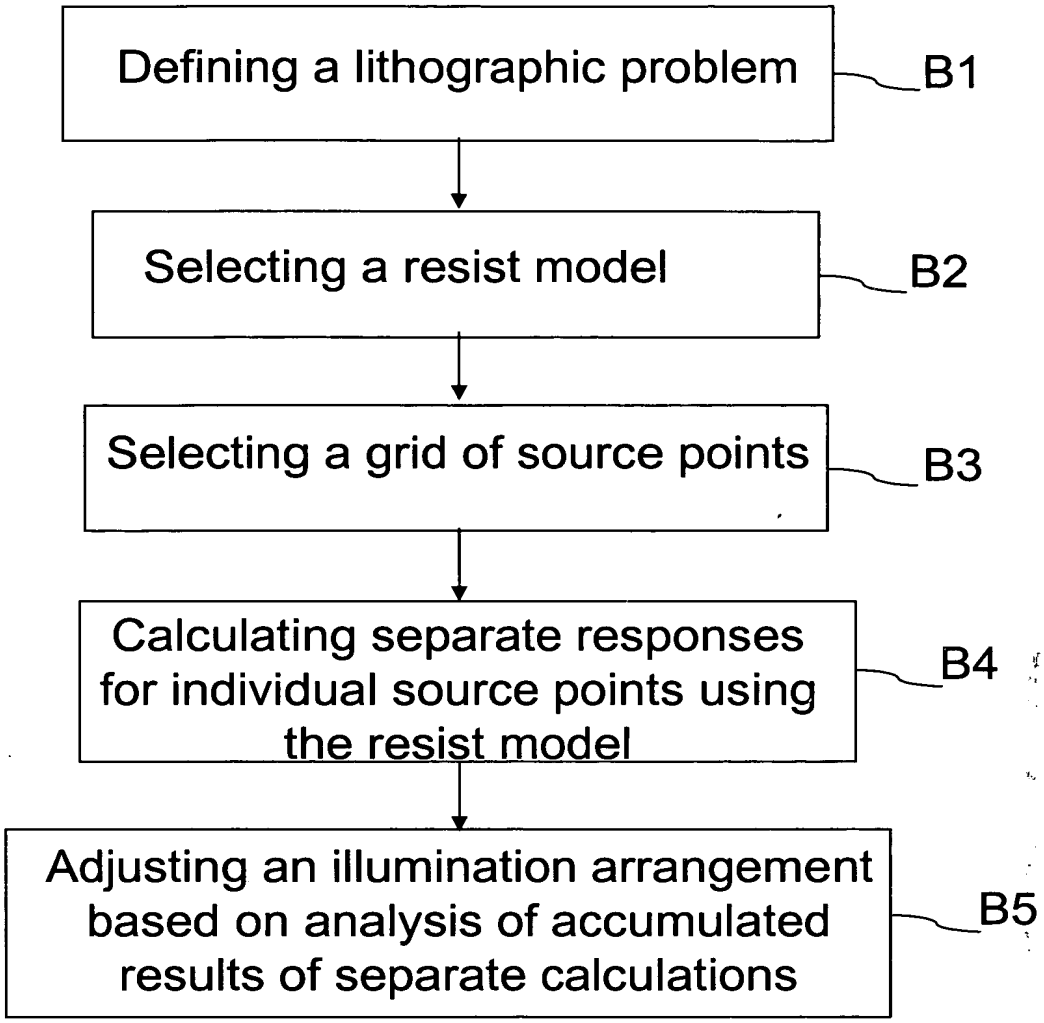

Defining a lithographic problem
B1
Selecting a resist model
B2
Selecting a grid of source points
B3
Calculating separate responses for individual source points using the resist model
B4
Adjusting an illumination arrangement based on analysis of accumulated results of separate calculations
B5

FIG. 16

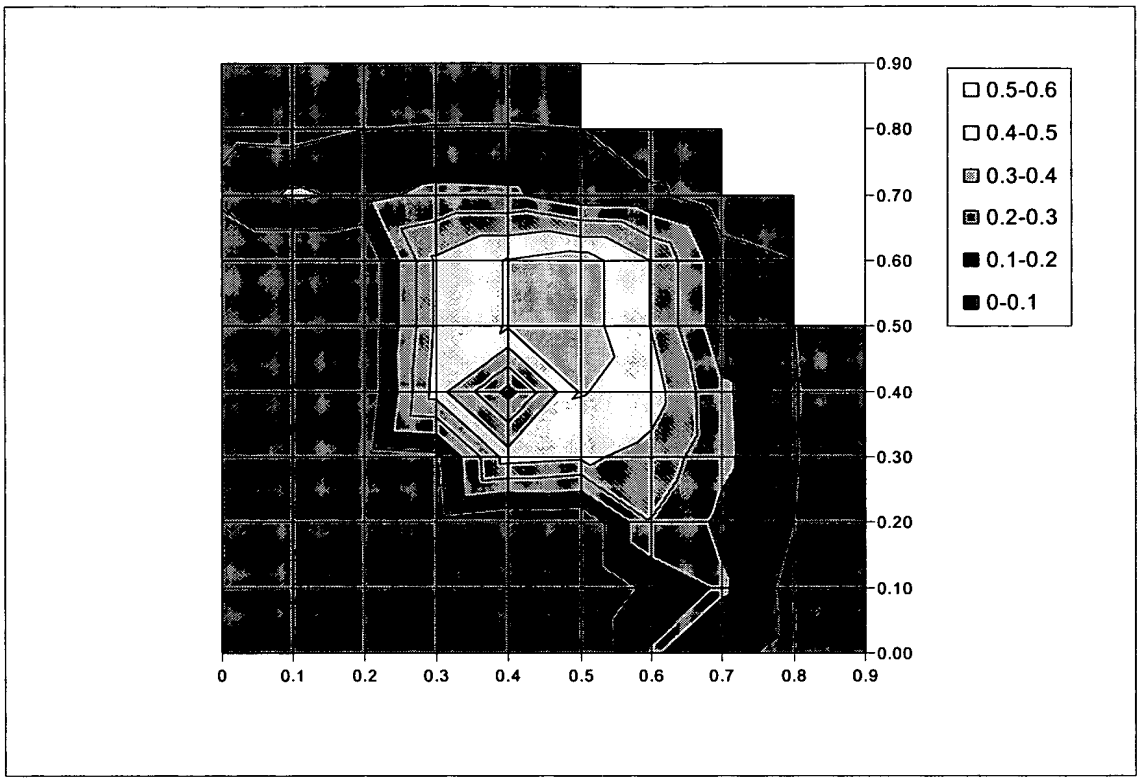

65nm CPL isolated lines, 193nm
0.85NA, TOK63 vector resist simulations
0.5-0.6
0.4-0.5
0.3-0.4
0.2-0.3
0.1-0.2
0-0.1
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

FIG. 17

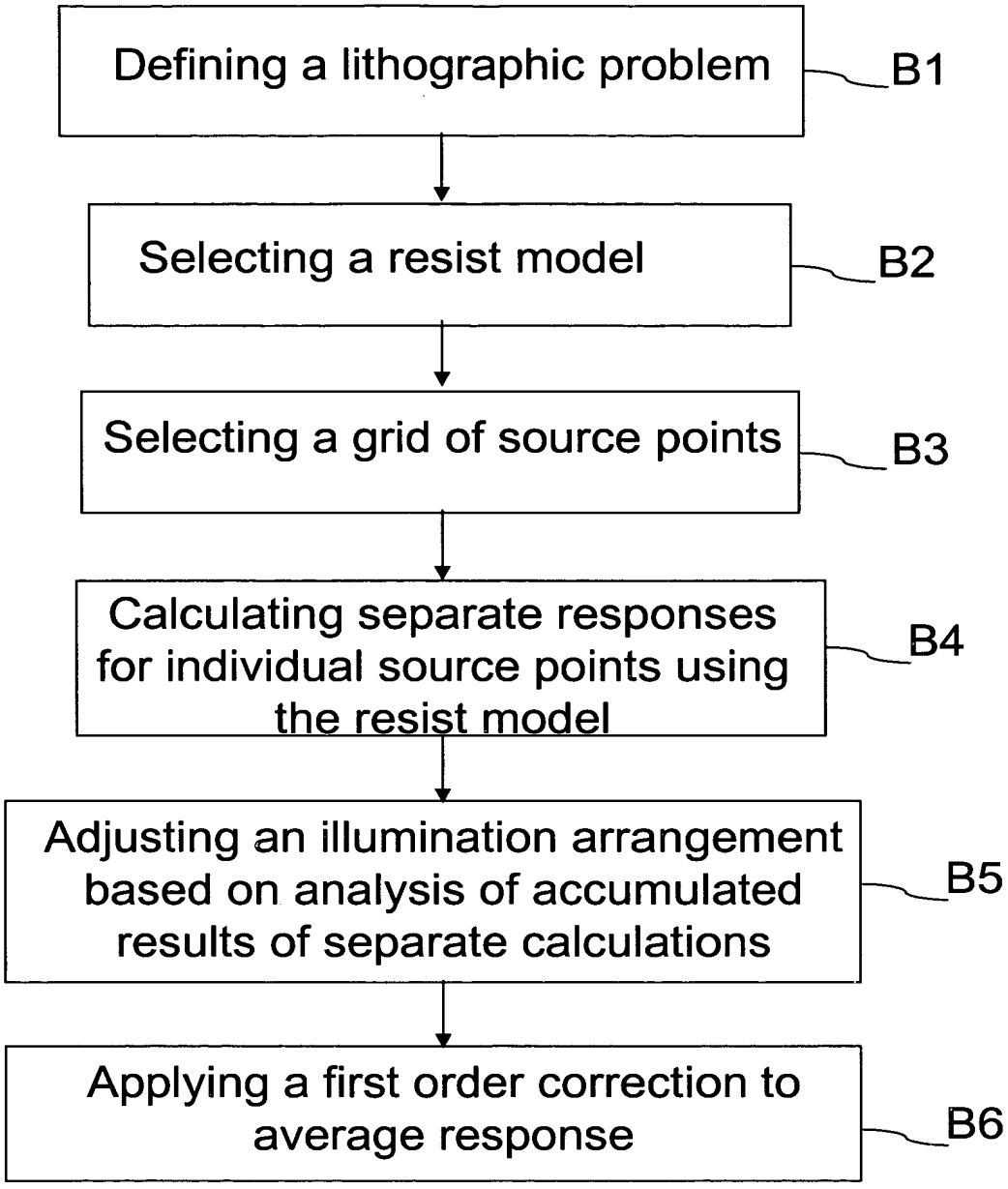

Defining a lithographic problem
B1
Selecting a resist model
B2
Selecting a grid of source points
B3
Calculating separate responses for individual source points using the resist model
B4
Adjusting an illumination arrangement based on analysis of accumulated results of separate calculations
B5
Applying a first order correction to average response
B6

FIG. 18

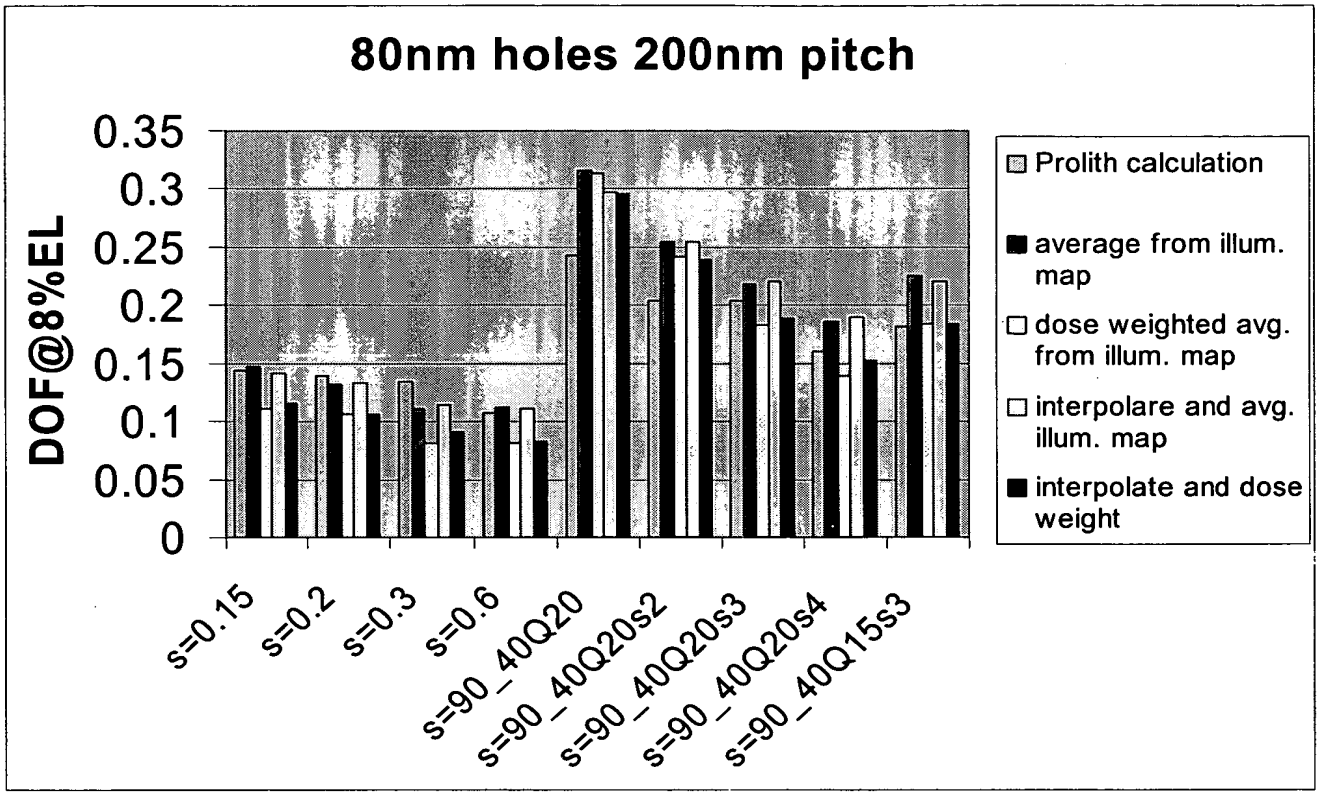
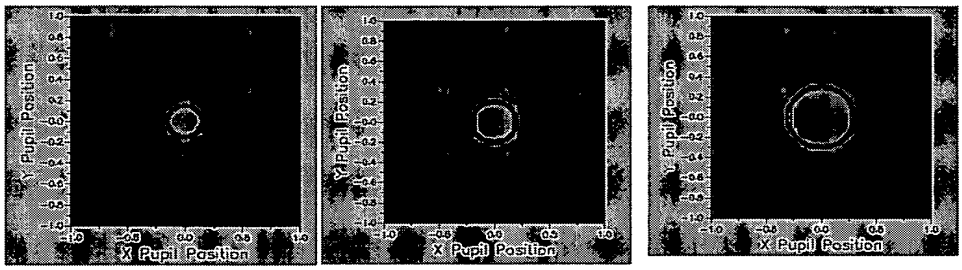
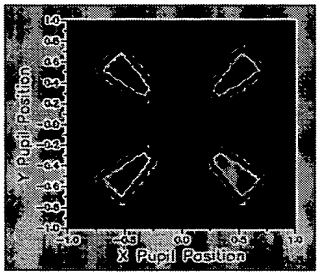

80nm holes 200nm pitch
DOF@8%EL
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
s=0.15
s=0.2
s=0.3
s=0.6
s=90_40Q20
s=90_40Q20s2
s=90_40Q20s3
s=90_40Q20s4
s=90_40Q15s3
Prolith calculation
average from illum. map
dose weighted avg. from illum. map
interpolare and avg. illum. map
interpolate and dose weight

FIG. 19

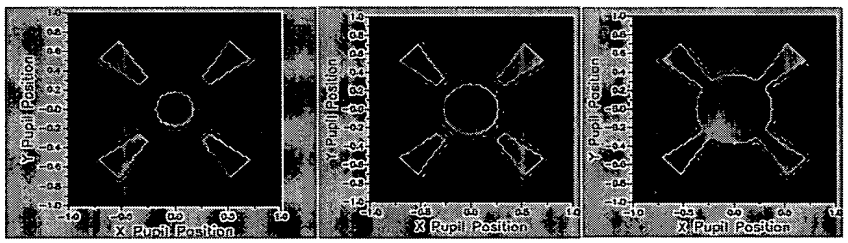
- 0.15, 0.2, 0.3, 0.6σ conv



- 0.9/0.4 Q20



- 0.2, 0.3, 0.4σ + 0.9/0.4 Q20



- 0.3σ + 0.9/0.4 Q15

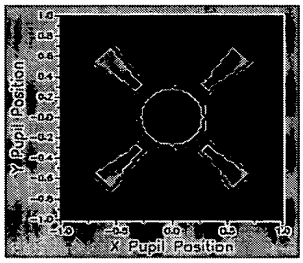


FIG. 20

trial illuminator	prediction based on weighted and interpolated source measurements	Prolith simulation with this illuminator
0.85_0.55Q30	0.293u	0.23u
0.75_0.55Q20	0.416	0.41
0.80_0.60Q20	0.383	0.355
0.80_0.60annular	0.110	0.10
0.75_0.55annular	0.118	0.105

FIG. 21

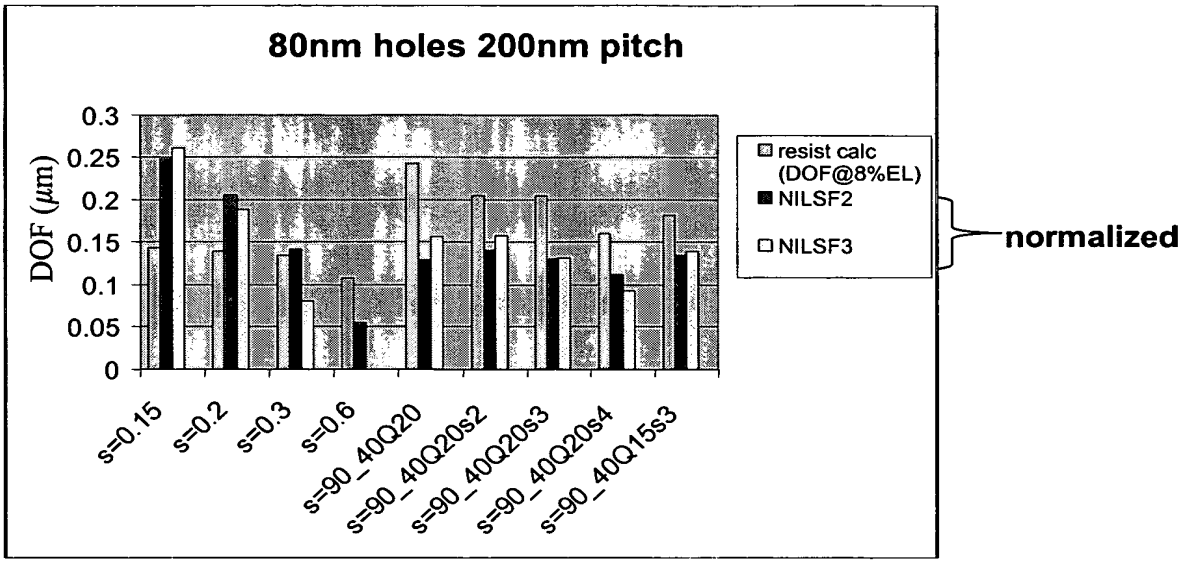

80nm holes 200nm pitch
DOF (μm)
0.3
0.25
0.2
0.15
0.1
0.05
0
s=0.15
s=0.2
s=0.3
s=0.6
s=90_40Q20
s=90_40Q20s2
s=90_40Q20s3
s=90_40Q20s4
s=90_40Q15s3
resist calc (DOF@8%EL)
NILSF2
NILSF3
normalized

FIG. 22

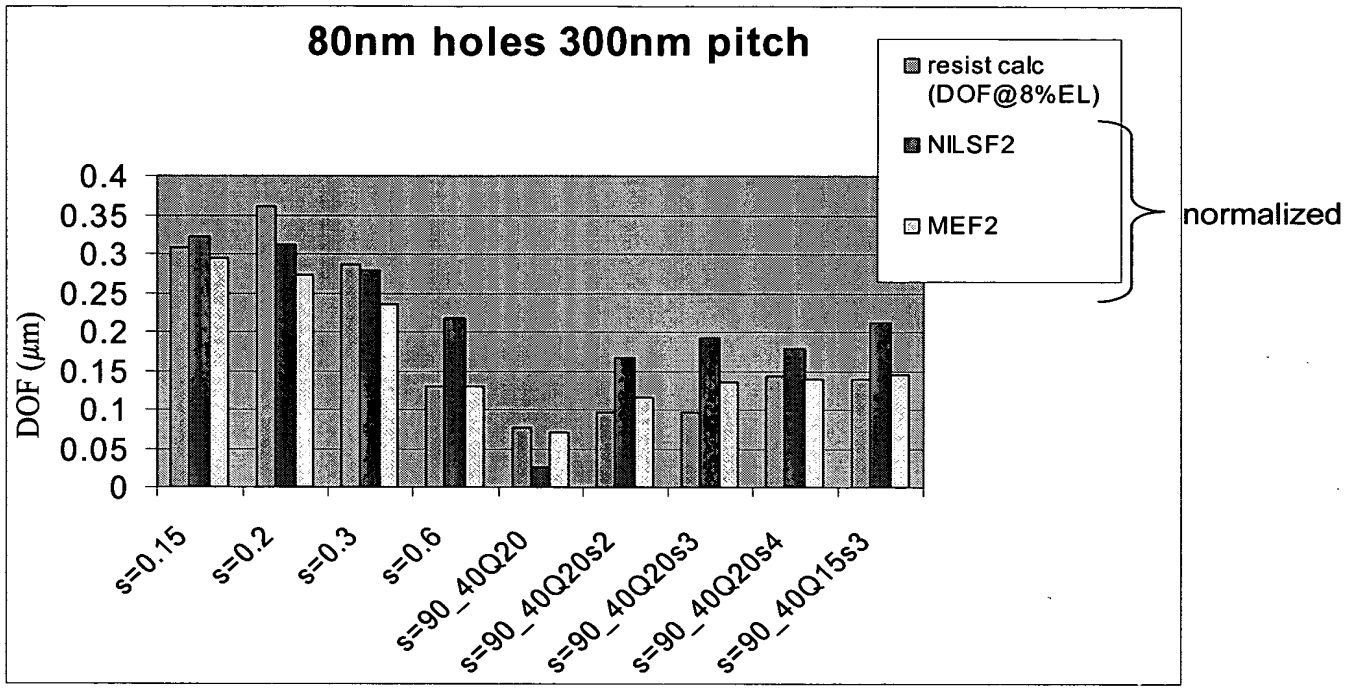

80nm holes 300nm pitch
resist calc (DOF@8%EL)
NILSF2
MEF2
normalized
DOF (μm)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
s=0.15
s=0.2
s=0.3
s=0.6
s=90_40Q20
s=90_40Q20s2
s=90_40Q20s3
s=90_40Q20s4
s=90_40Q15s3

FIG. 23

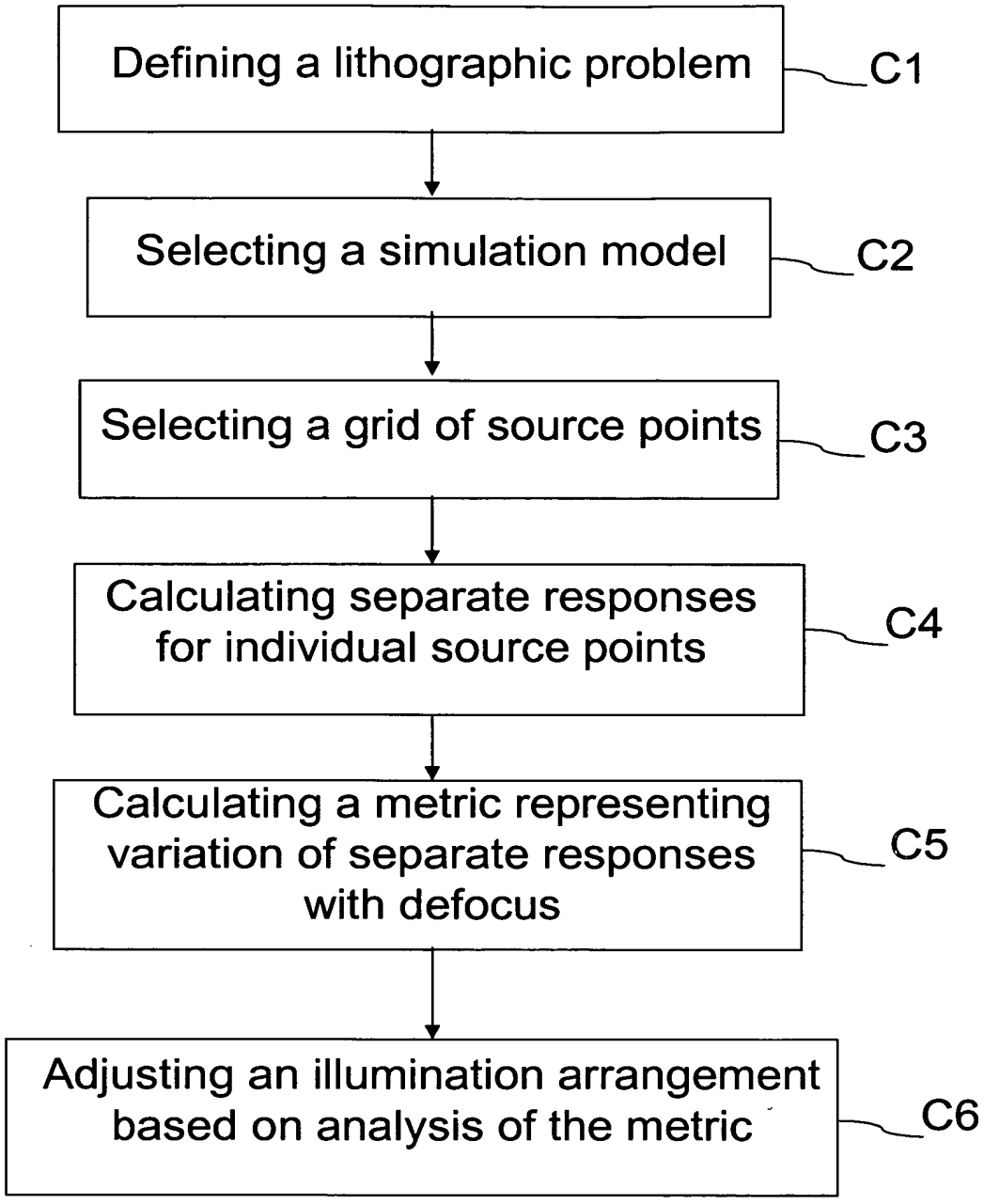

Defining a lithographic problem
C1
Selecting a simulation model
C2
Selecting a grid of source points
C3
Calculating separate responses for individual source points
C4
Calculating a metric representing variation of separate responses with defocus
C5
Adjusting an illumination arrangement based on analysis of the metric
C6

FIG. 24

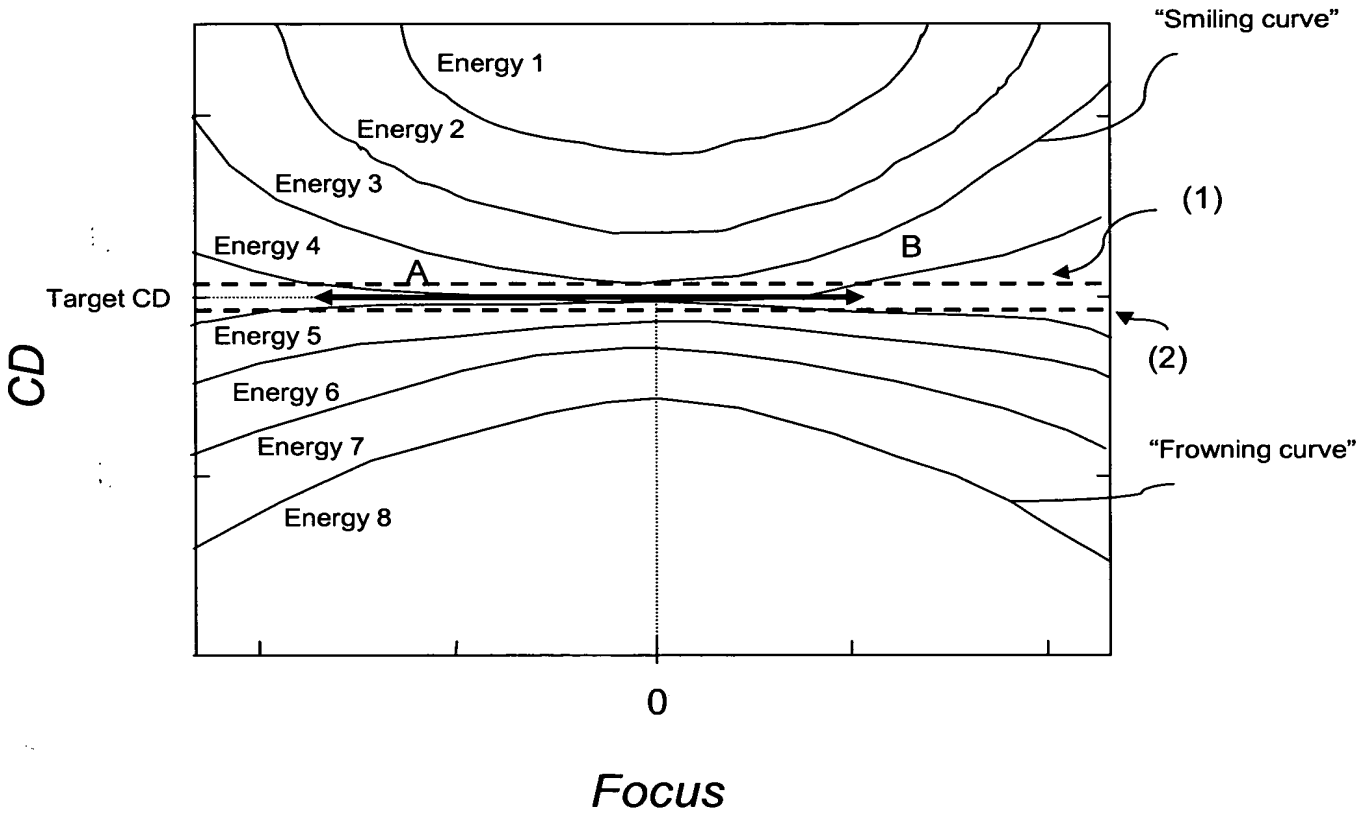

"Smiling curve"
Energy 1
Energy 2
Energy 3
(1)
Energy 4
B
A
Target CD
Energy 5
(2)
Energy 6
Energy 7
"Frowning curve"
Energy 8
CD
0
Focus

FIG. 25

resist calculation CD(BF+0.2)-CD(BF)

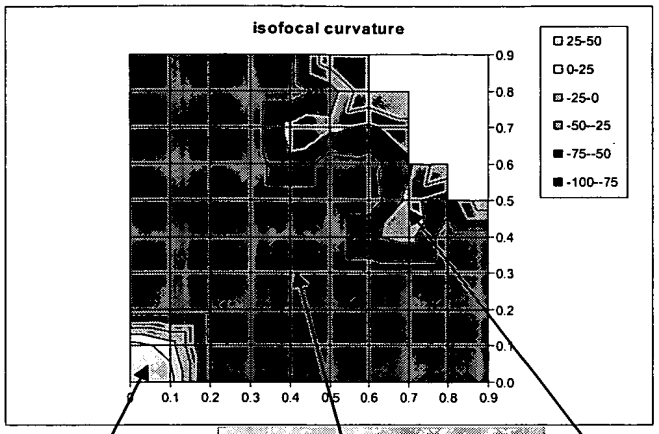


FIG. 26a

Area where Bossung "smiles" CD(=0.2)>CD(f=0)

Area where Bossung "frowns" severely hole closed at 0.2u defocus

Area where Bossung "frowns" less severely

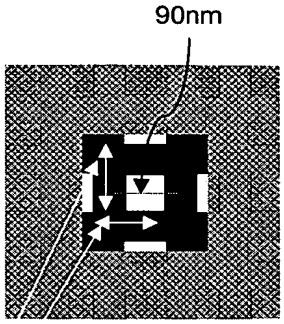


FIG. 26c

Aerial image calculation thresh(BF)-thresh(BF+0.2)

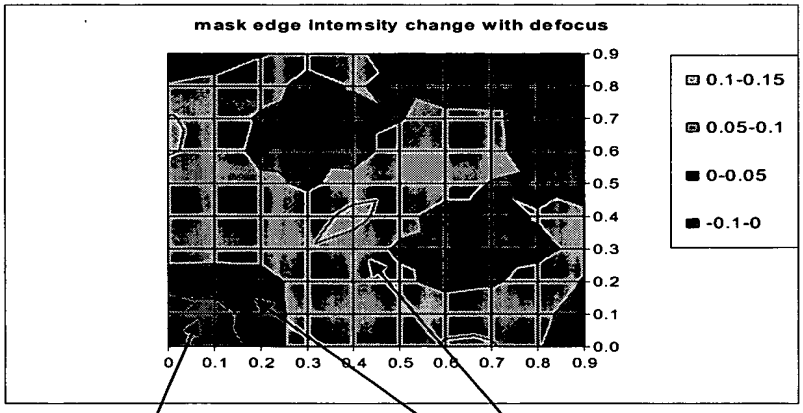


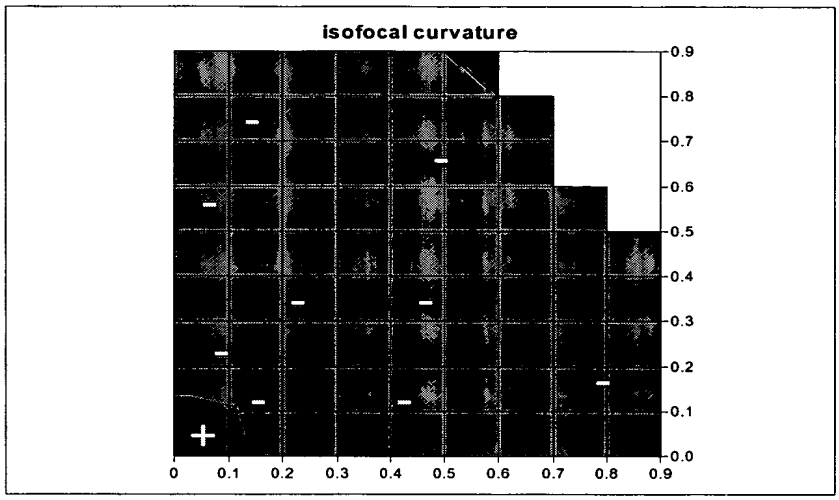
FIG. 26b

Area where image CD is larger in defocus

Area where image CD is smaller in defocus

resist calculation CD(BF+0.2)-CD(BF)

FIG. 27a



Aerial image calculation thresh(BF)-thresh(BF+0.2)

FIG. 27b

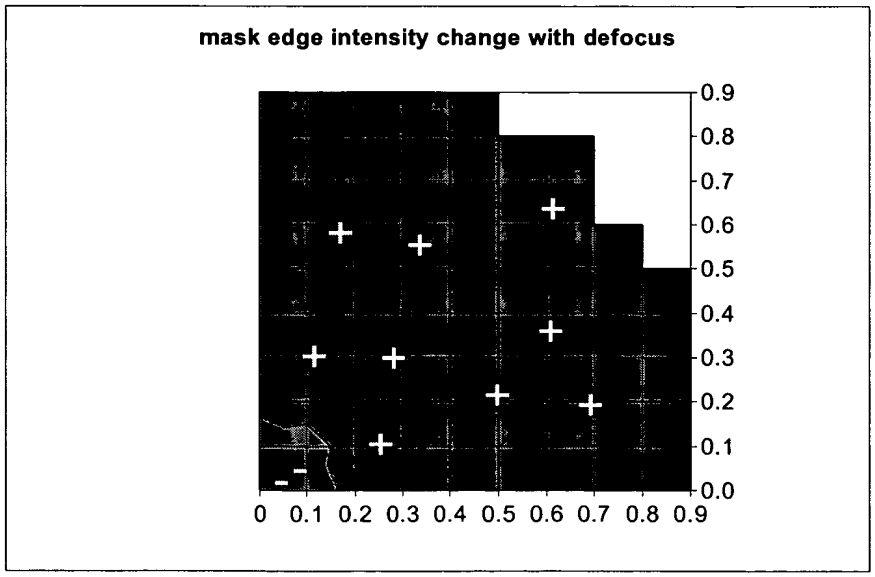
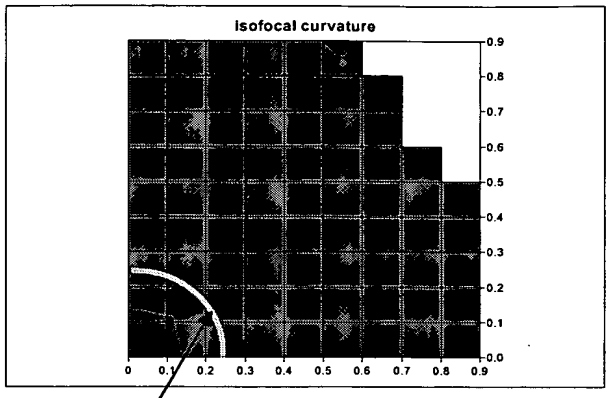


FIG. 28



σ=0.25 combines areas of + and - isofocal curvature

At σ=0.25, process is approximately isofocal. DOF is good but dose latitude is low.

FIG. 29

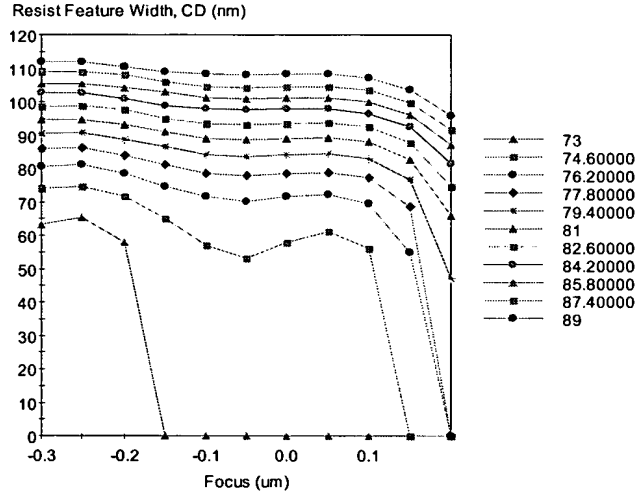
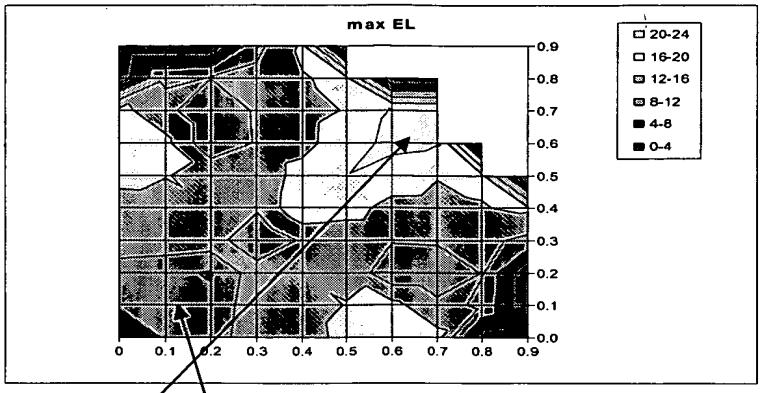


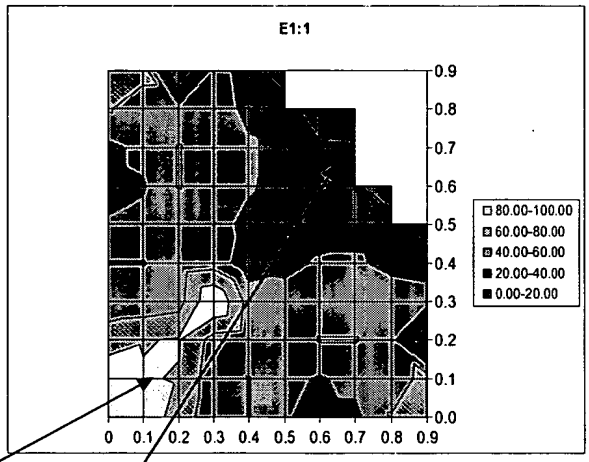
FIG. 30a



Low σ area provides poor EL and also requires high dose to print (weak aerial image)

Desirable area for high EL is wide quasar

FIG. 30b



Low σ area provides poor EL and also requires high dose to print (weak aerial image)

Wide quasar also provides low E1:1 (strong aerial image)

Illuminator = σ(0.1 conv) + (0.92/0.88Q5°)

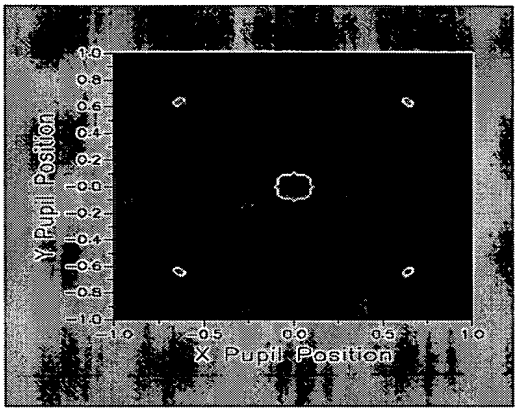


FIG. 31

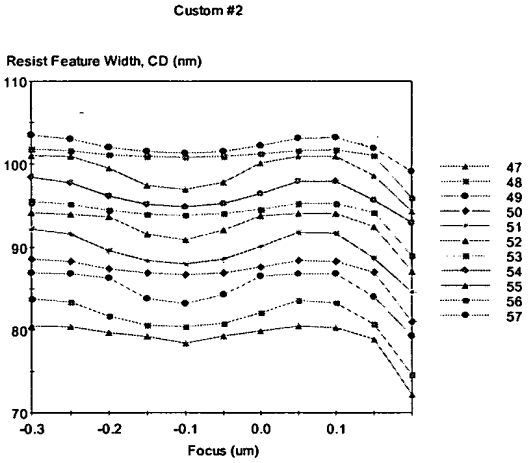


FIG. 32

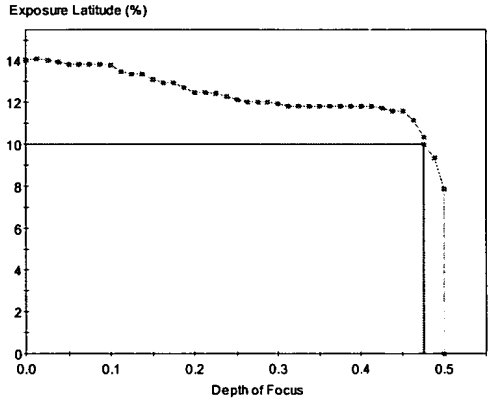


FIG. 33

optimization method	illumination	max EL	max DOF	DOF @ 10% EL	DOF @ 5% EL
standard	0.95/0.70Q30°	18%	0.3	0.18	0.24
simple isofocal compensation	0.25 conv	8%	>0.55	0	0.29
high EL isofocal compensation	0.92/0.88Q5°+0.1conv	16%	>0.65	0.57	0.63

FIG. 34

Large improvement in process window may be possible by appropriate use of illuminator to compensate isofocal curvature

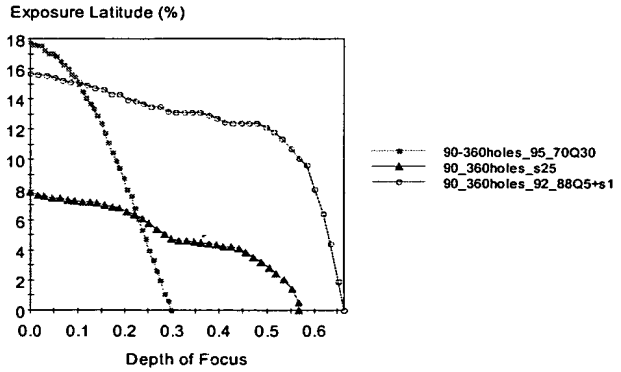


FIG. 35a

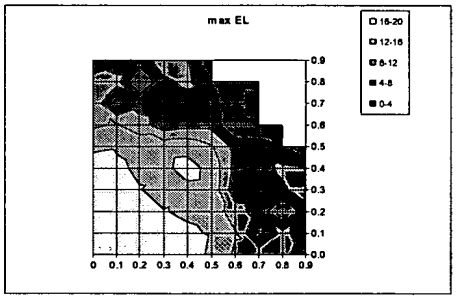


FIG. 35b

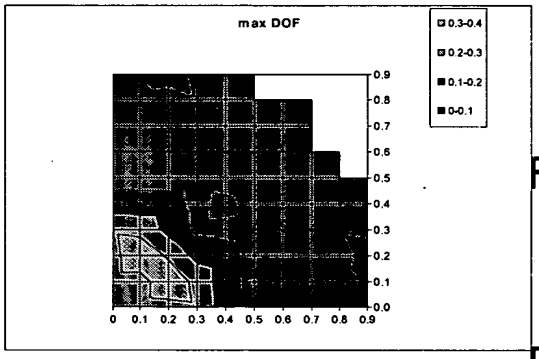
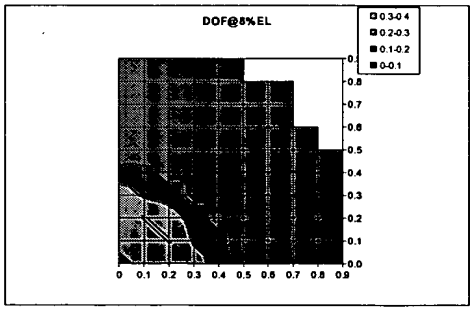


FIG. 35d

FIG. 35c



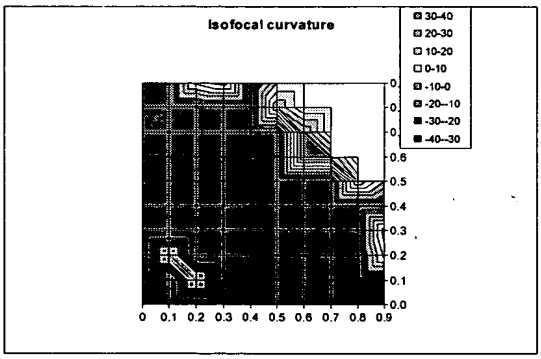


FIG. 36a

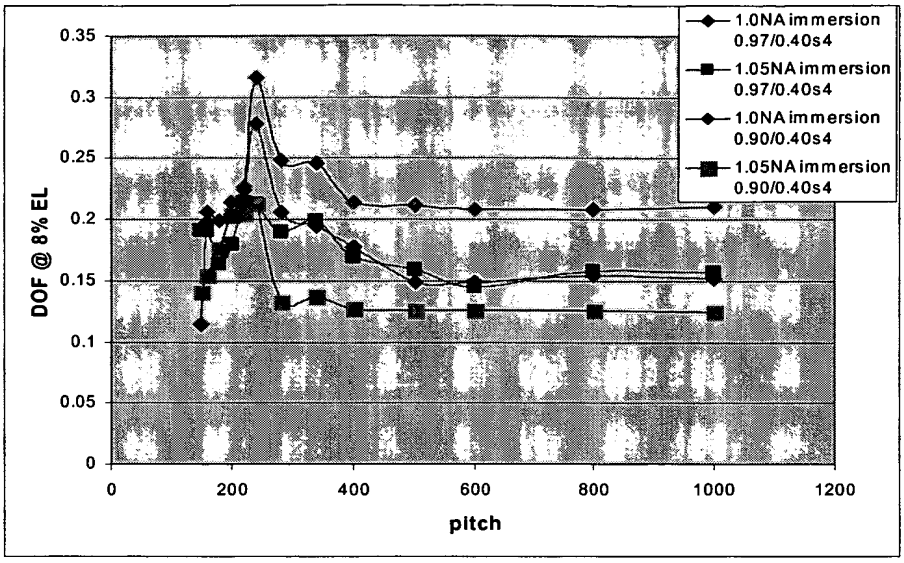
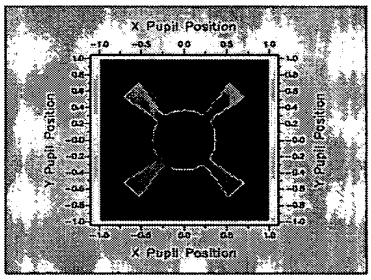


FIG. 36b

0.90/0.40+0.4σ



0.97/0.40+0.4σ

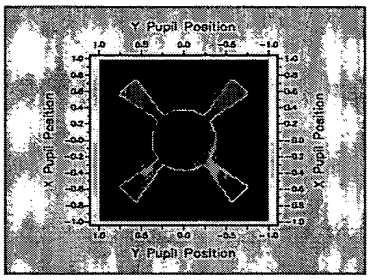


FIG. 36c

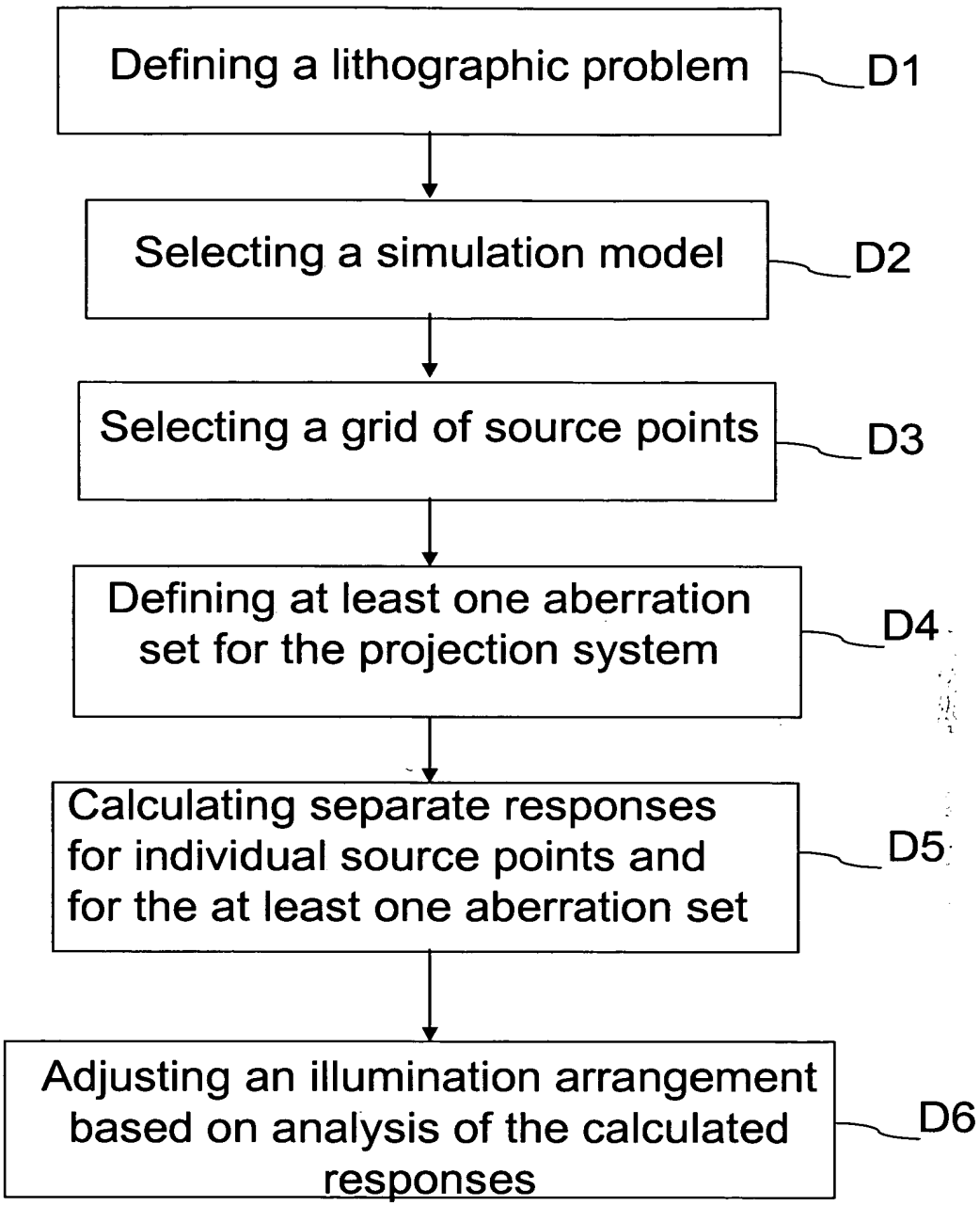

Defining a lithographic problem
D1
Selecting a simulation model
D2
Selecting a grid of source points
D3
Defining at least one aberration set for the projection system
D4
Calculating separate responses for individual source points and for the at least one aberration set
D5
Adjusting an illumination arrangement based on analysis of the calculated responses
D6

FIG. 37

Under these conditions, the structure
is very aberration sensitive

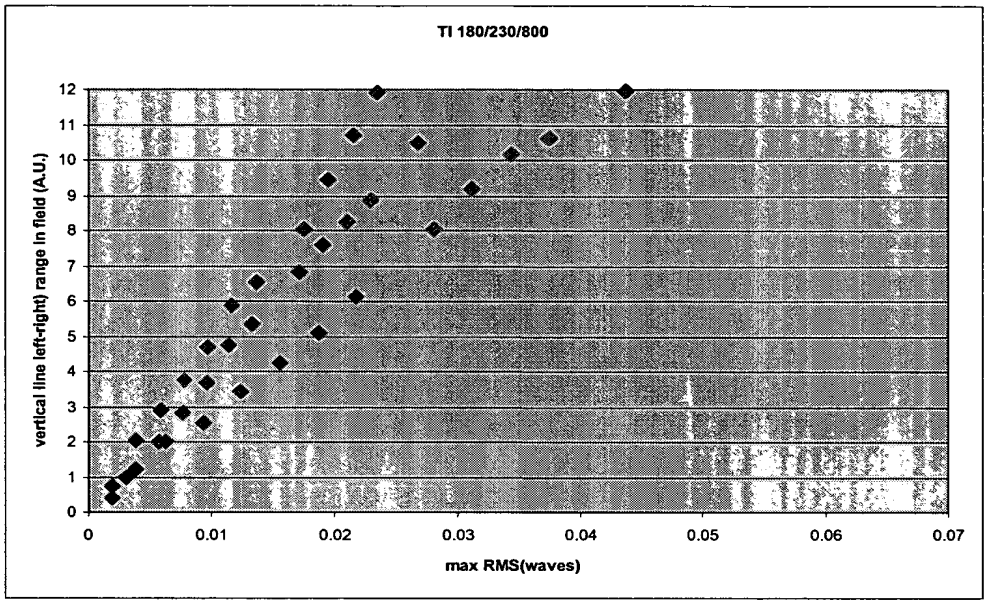


FIG. 38a

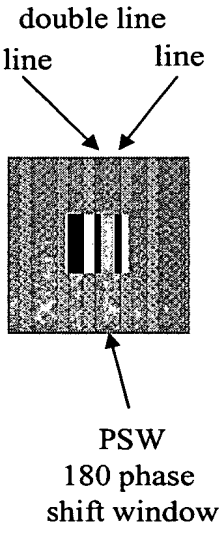


FIG. 38b

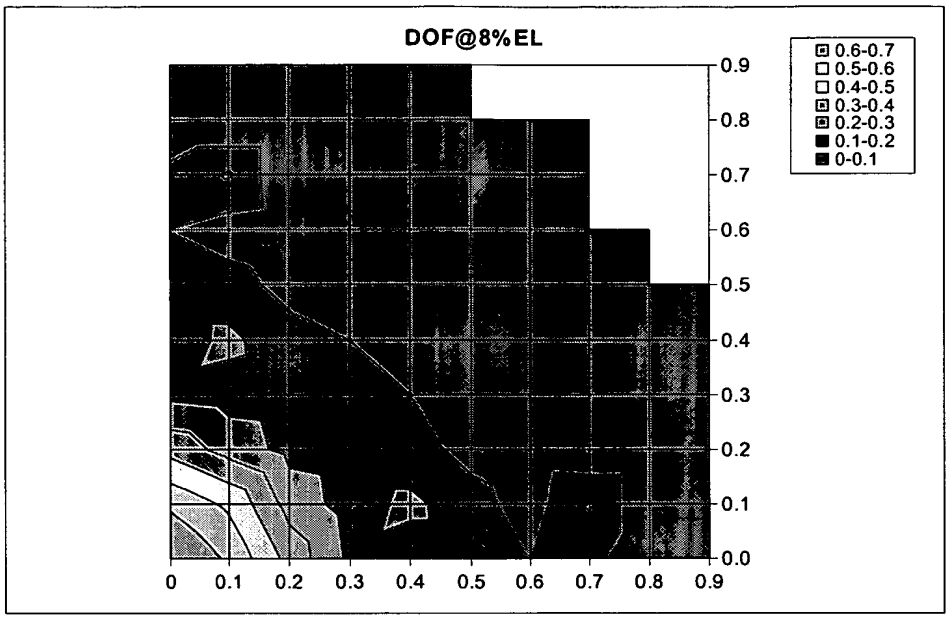


FIG. 39a

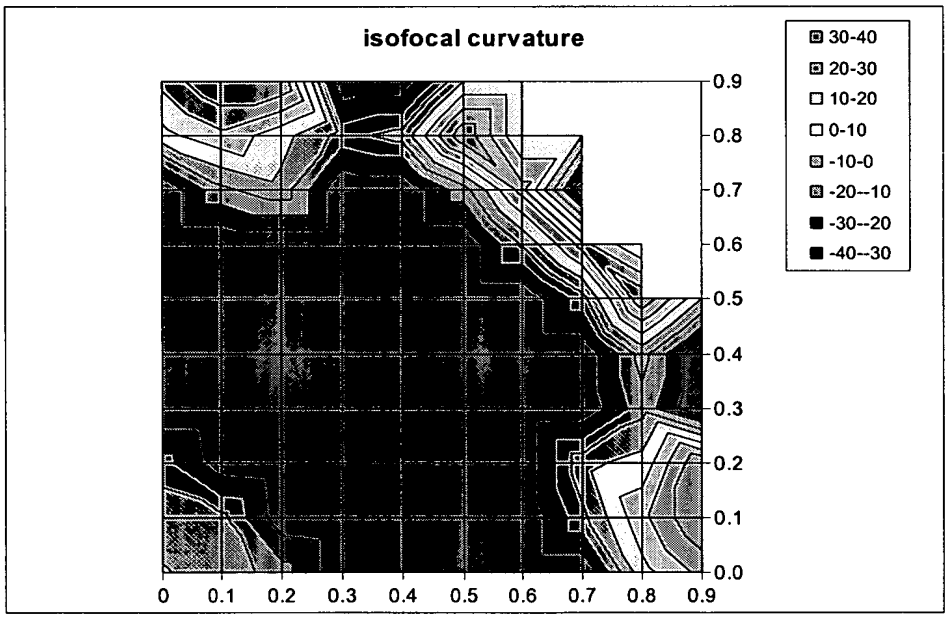
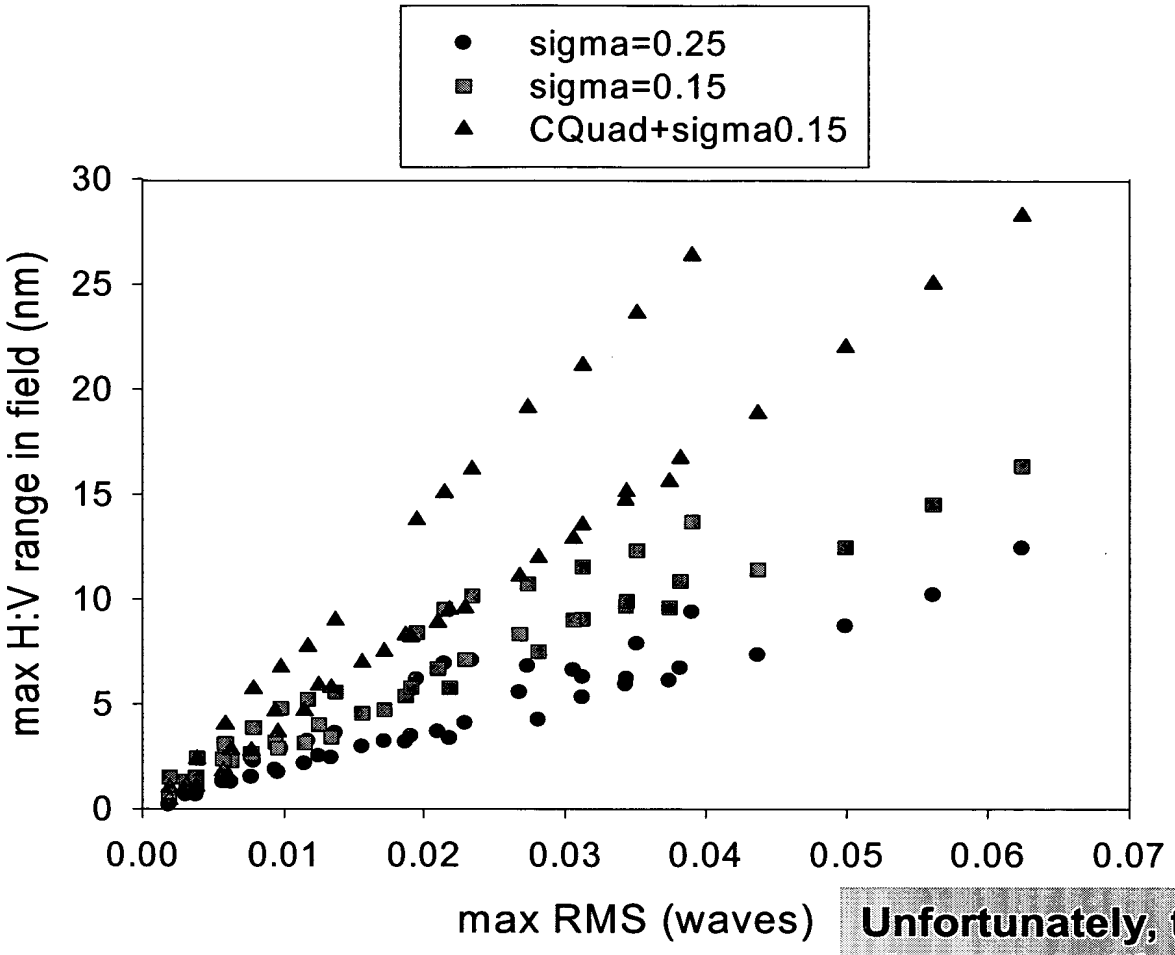


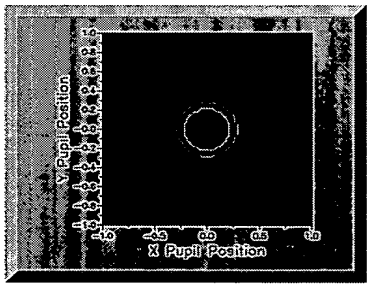
FIG. 39b

Illuminator comparison for double line

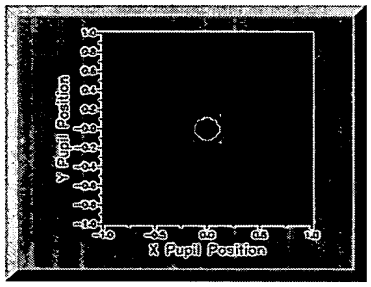


Unfortunately, the alternate settings have higher aberration sensitivity.

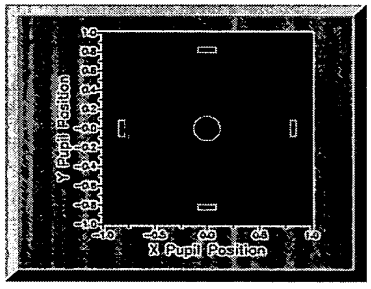
FIG. 40



σ=0.25



σ=0.15



σ=0.15 +
small Cquad

FIG. 41

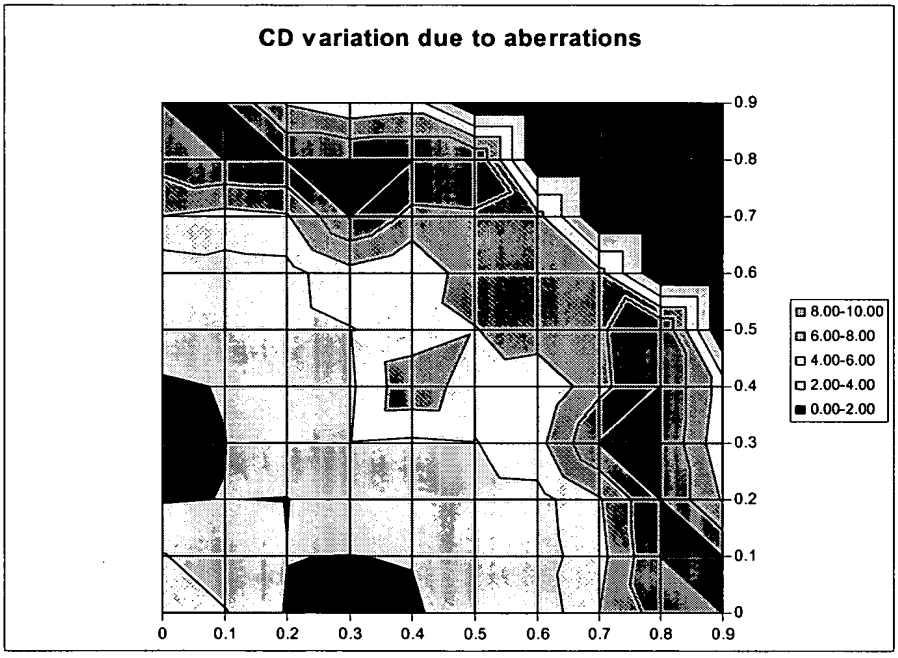
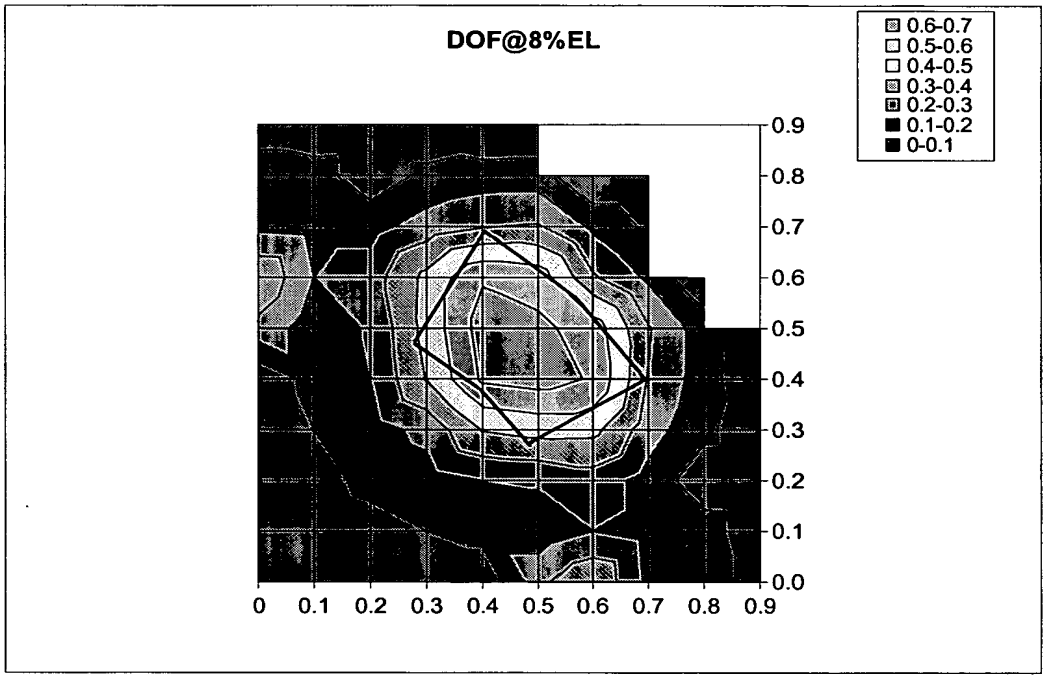

CD variation due to aberrations
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
8.00-10.00
6.00-8.00
4.00-6.00
2.00-4.00
0.00-2.00

FIG. 42

Illum. Optimization with 0.75NA

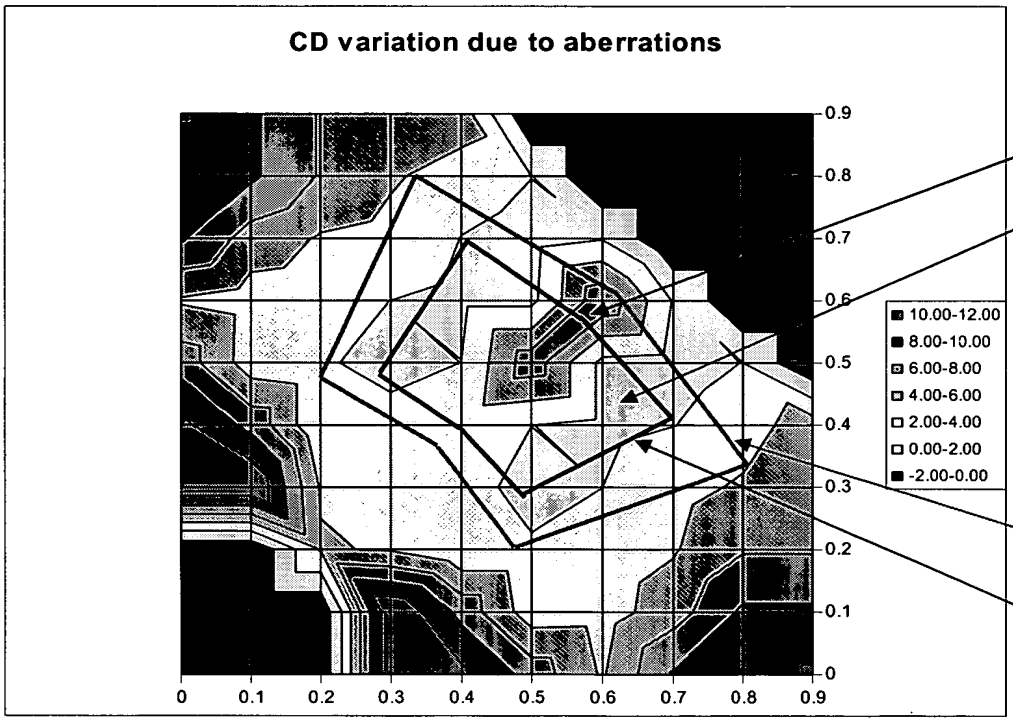


tight Quasar looks best

$\Rightarrow$ 0.80/0.55Q30°

FIG. 43

Source visualization of aberration sensitivity



High aberration sensitivity (6-8nm variation) for exactly 45° quasar location. Sensitivity drops (0-2nm) for "off axis points. Aberration sensitivity can be reduced by enlarging poles to dilute the unfavorable on-axis sensitivity; reduction in process window expected.

Also consider larger poles
⇒ 0.85/0.50Q45°
in addition to tight quasar
⇒ 0.80/0.55Q30°

FIG. 44

Illuminator comparison for double line

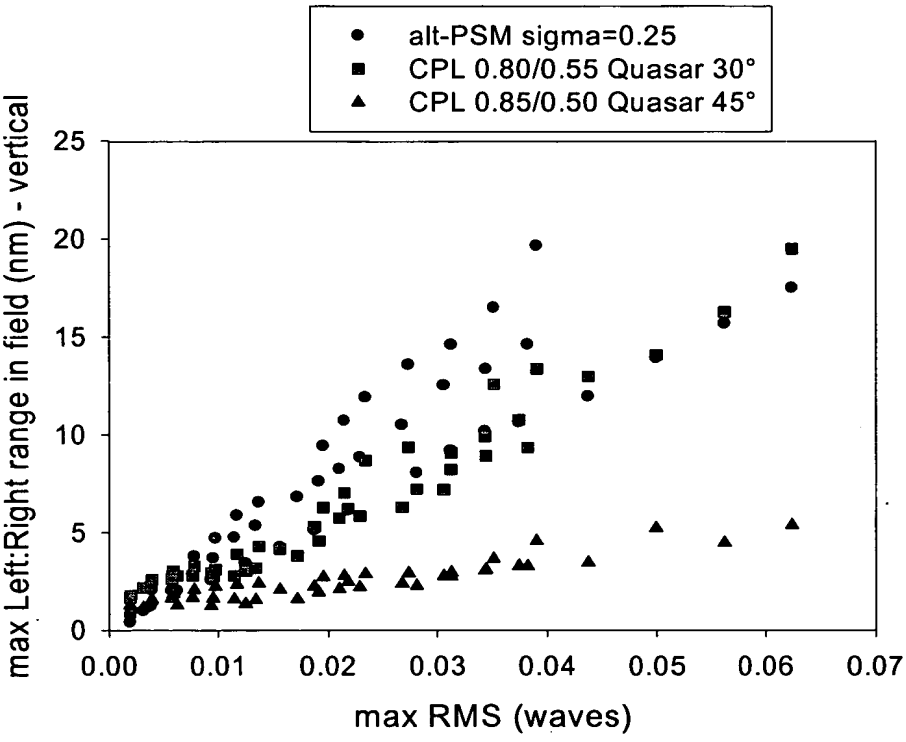


FIG. 45

CPL with reduced aberration sensitivity
increased pole size still gives favorable process window

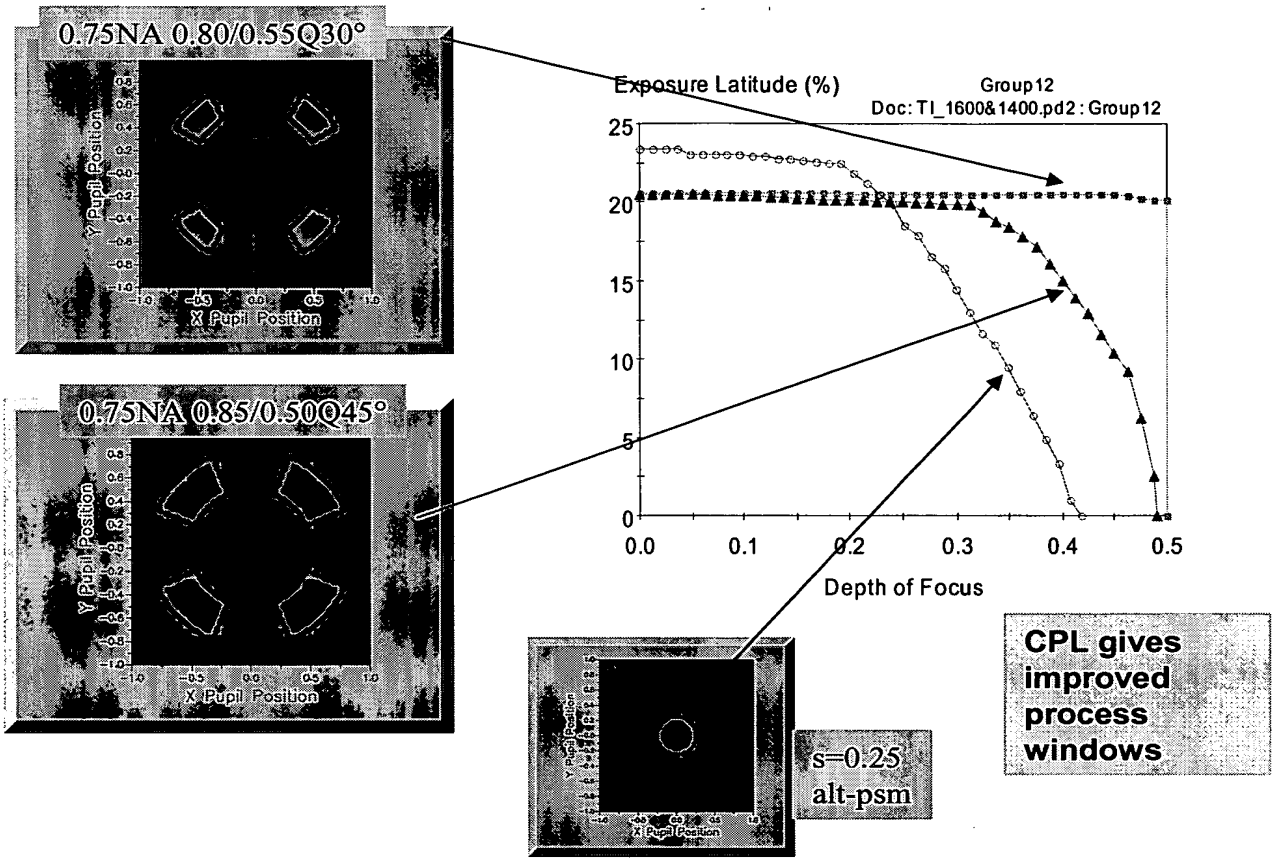


FIG. 46

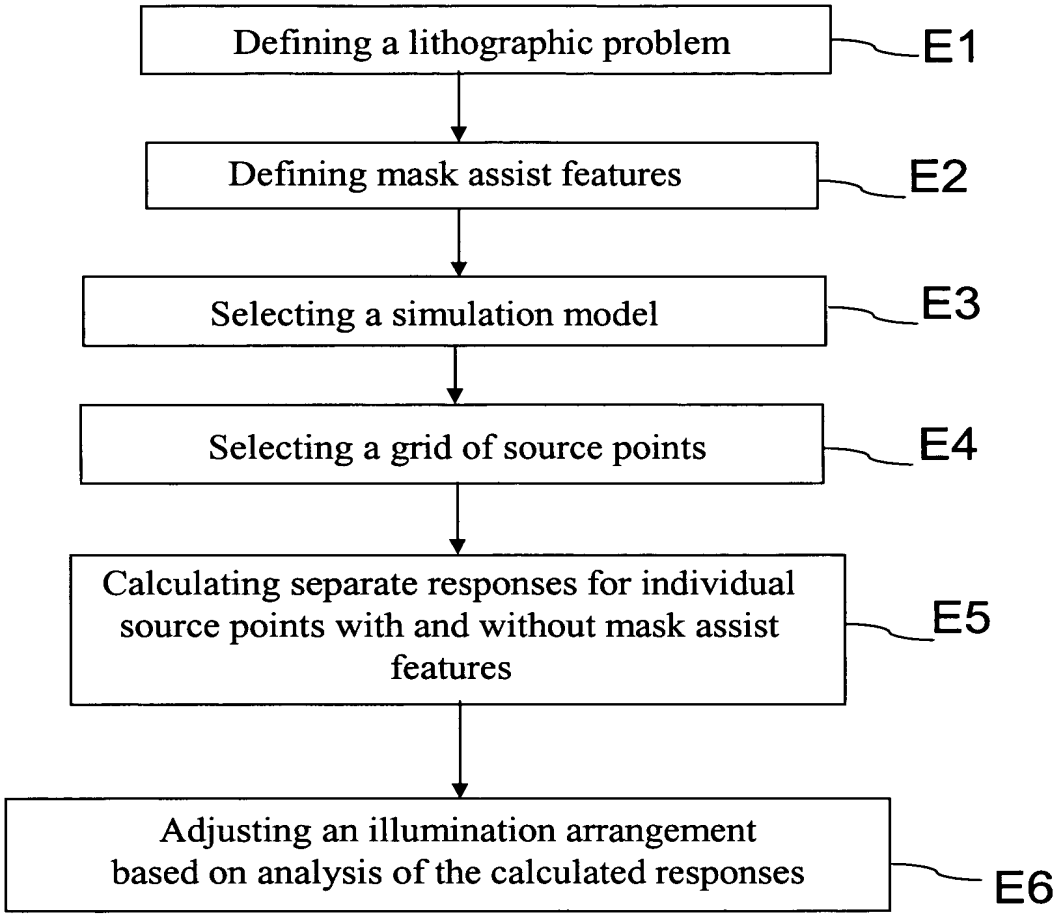

Defining a lithographic problem
E1
Defining mask assist features
E2
Selecting a simulation model
E3
Selecting a grid of source points
E4
Calculating separate responses for individual source points with and without mask assist features
E5
Adjusting an illumination arrangement based on analysis of the calculated responses
E6

FIG. 47

6%Att-PSM, 1Anti-Scatterring Bar (ASB)/side
50nm ASB, 150nm pitch

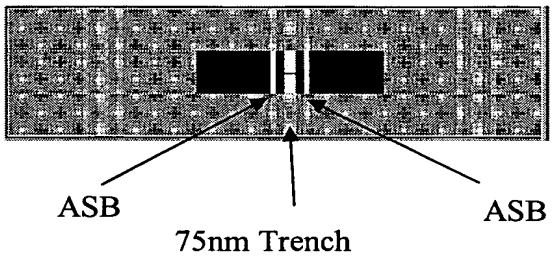


FIG. 48

Optimization requires very wide CQuad or quasar

75nm trench, 15nm bias
6% att-psm,193nm 0.93NA

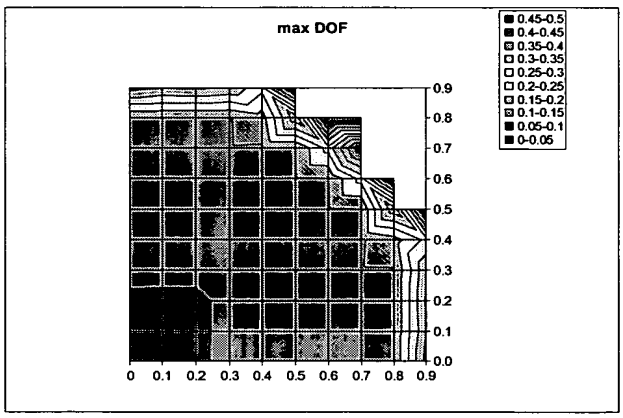


FIG. 49a

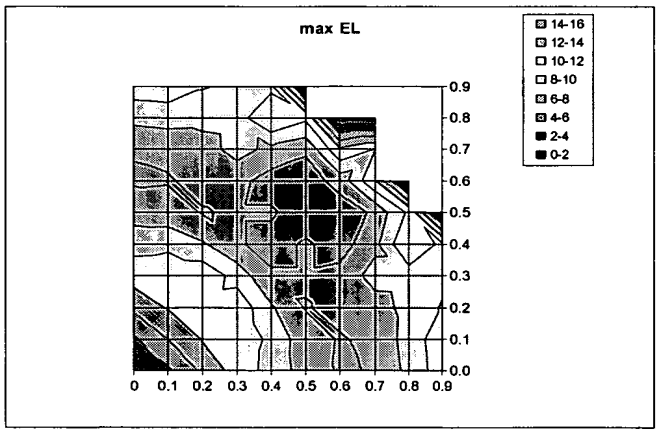


FIG. 49b

75nm trench, 15nm bias
6% att-psm, 193nm 0.93NA

1SB / side

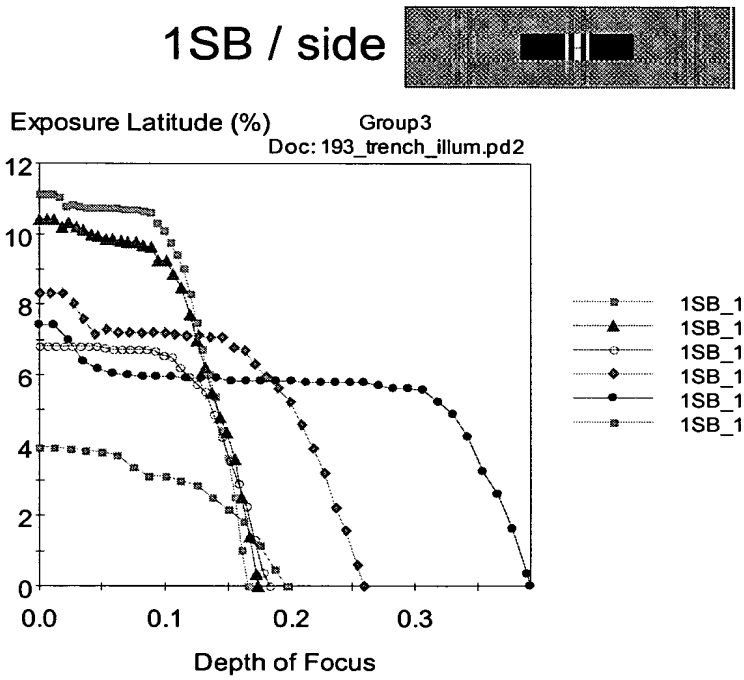
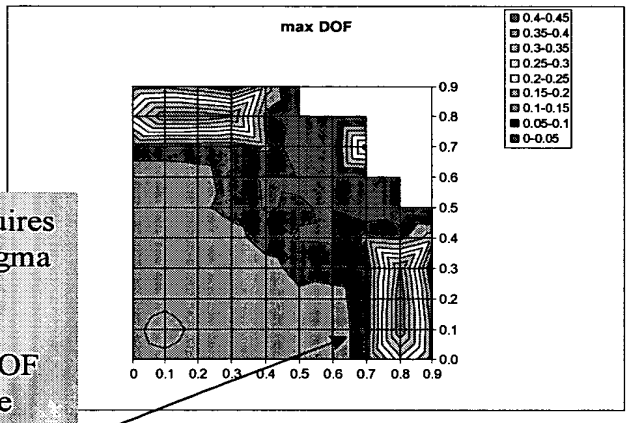


FIG. 50

6%Att-PSM



6% requires small sigma for dose latitude. Good DOF available with wide CQuad, but with poor dose latitude.

FIG. 51a

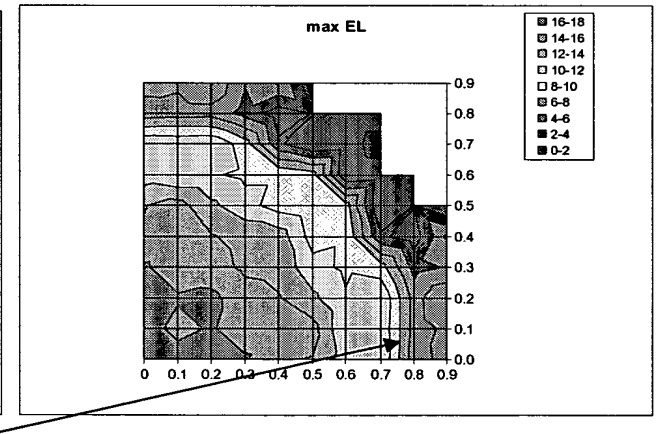


FIG. 51b

35°Cquad + 0.10σ

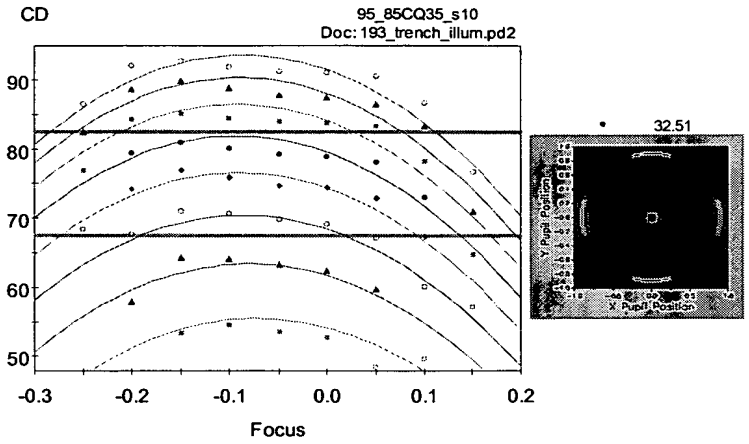


FIG. 52

Comparison of "mask assist" and "illuminator assist" for high DOF

- similar results

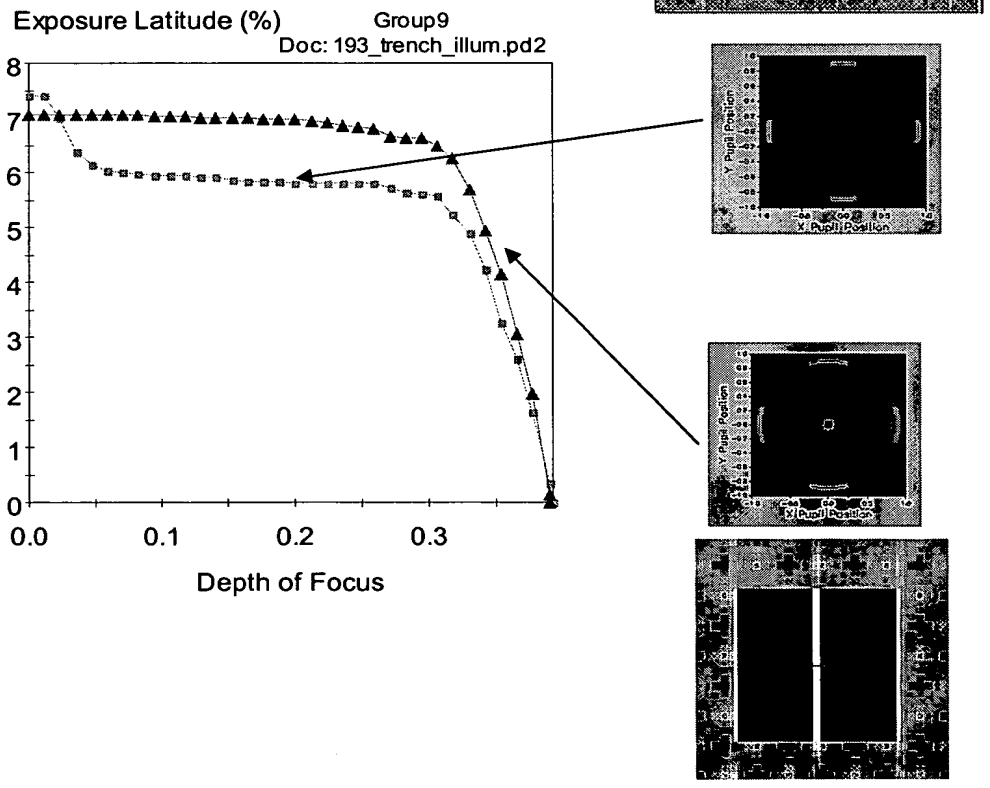
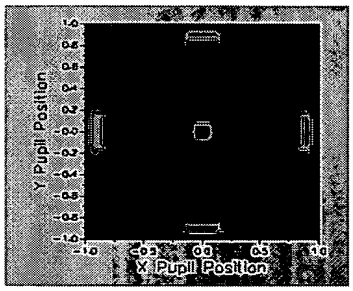
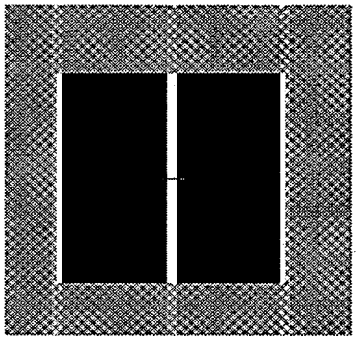


FIG. 53

Effect of bias

75nm trench, variable bias
6% att-psm, 193nm 0.93NA





• Lower bias increases DOF. This is an advantage for the "simple mask, complex illuminator" case because there are no assist features to print when using low biases / high exposures.

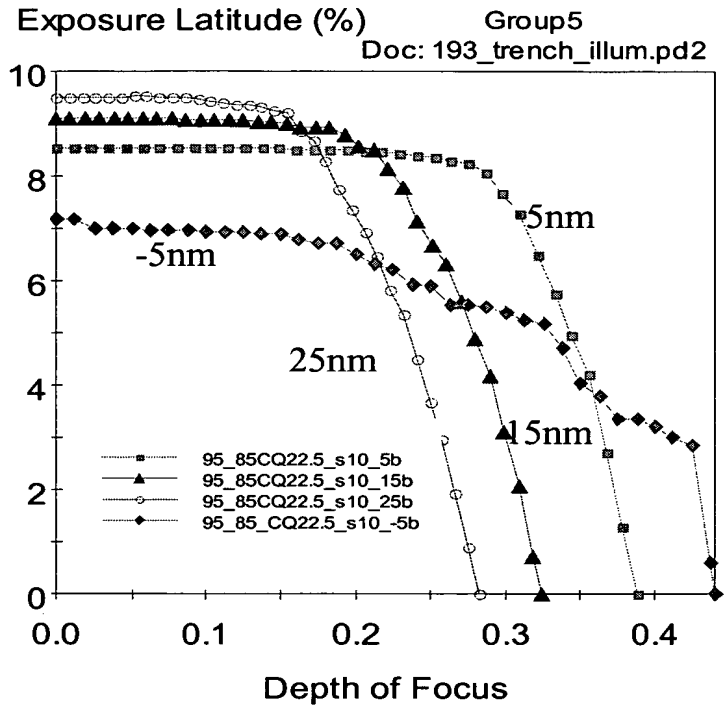


FIG.54

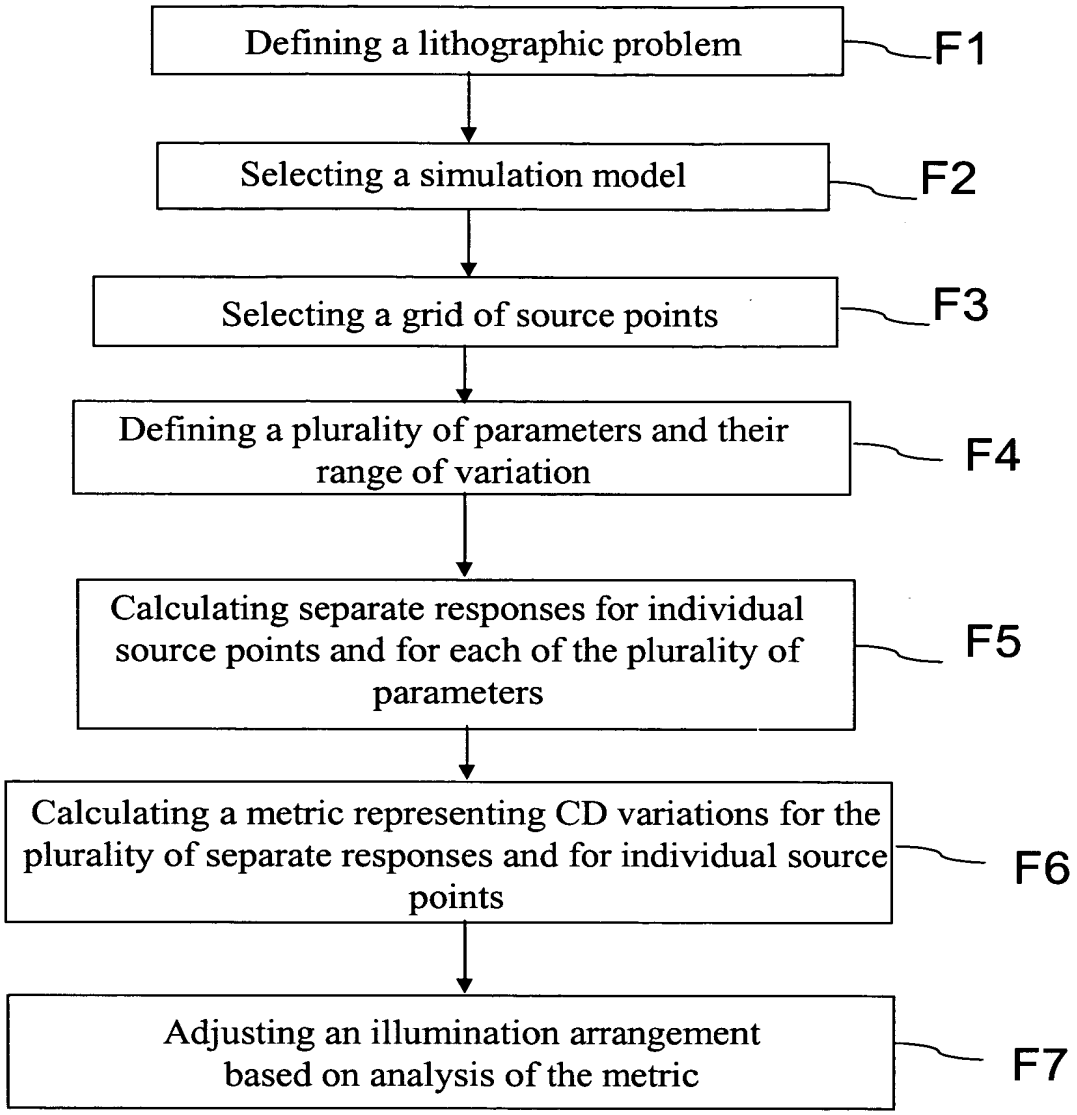

Defining a lithographic problem
F1
Selecting a simulation model
F2
Selecting a grid of source points
F3
Defining a plurality of parameters and their range of variation
F4
Calculating separate responses for individual source points and for each of the plurality of parameters
F5
Calculating a metric representing CD variations for the plurality of separate responses and for individual source points
F6
Adjusting an illumination arrangement based on analysis of the metric
F7

FIG. 55

CPL for double line

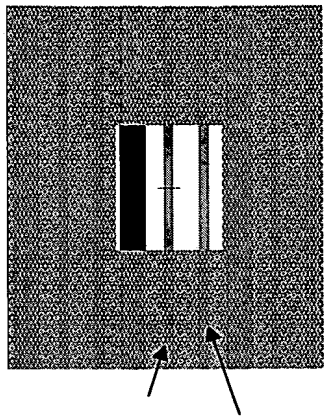
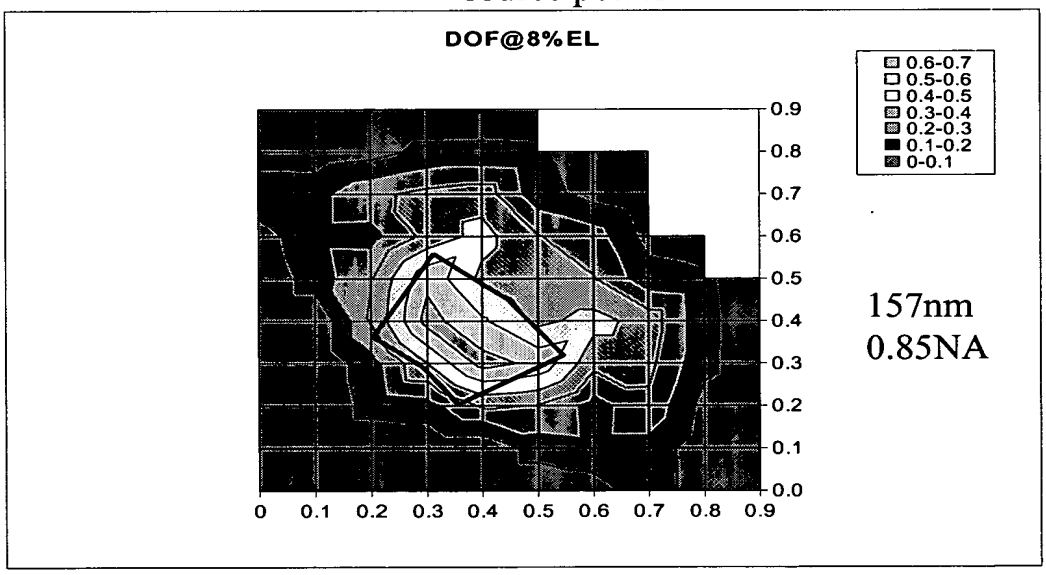


FIG. 56

Source visualization map
based on resist simulations for a grid of
source points



"Best choice" for illumination based on process window metric is the indicated 0.64/0.42Quasar30°.
Note: smaller poles centered at the same location expected to give better process window - larger worse.

FIG. 57

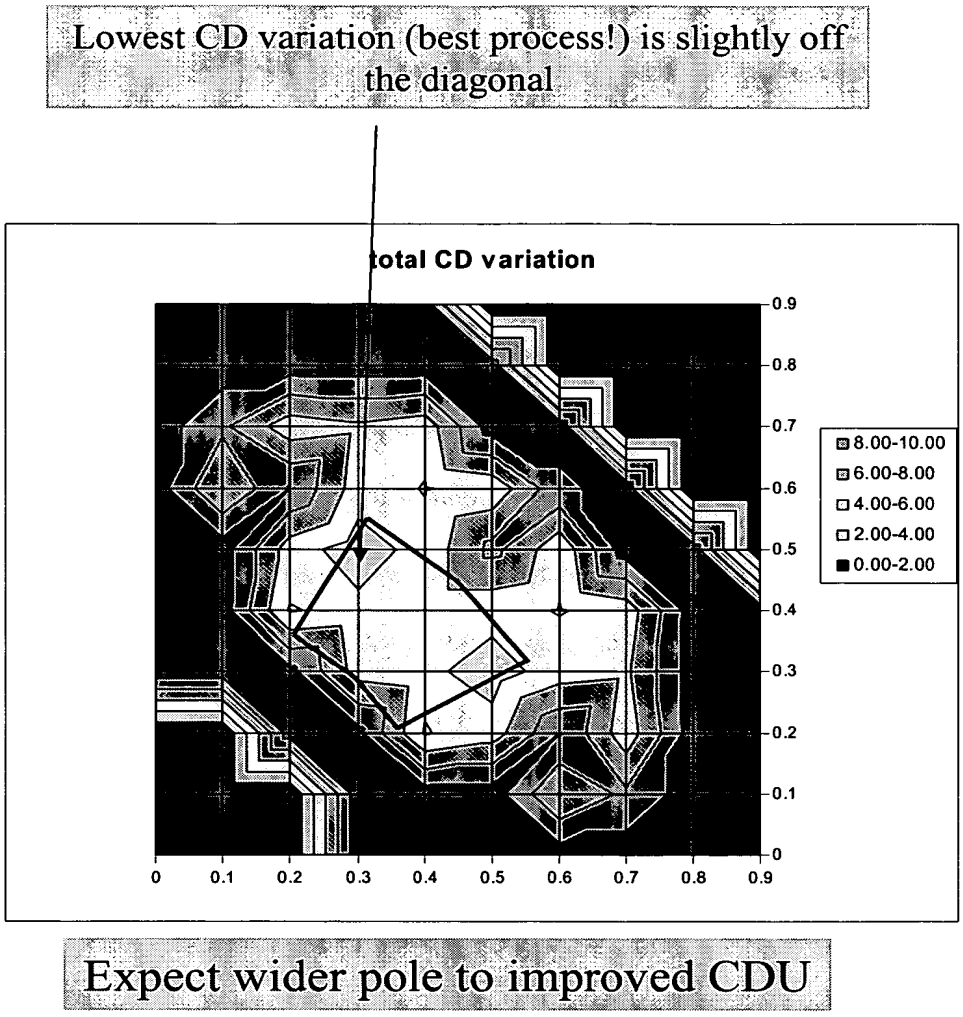
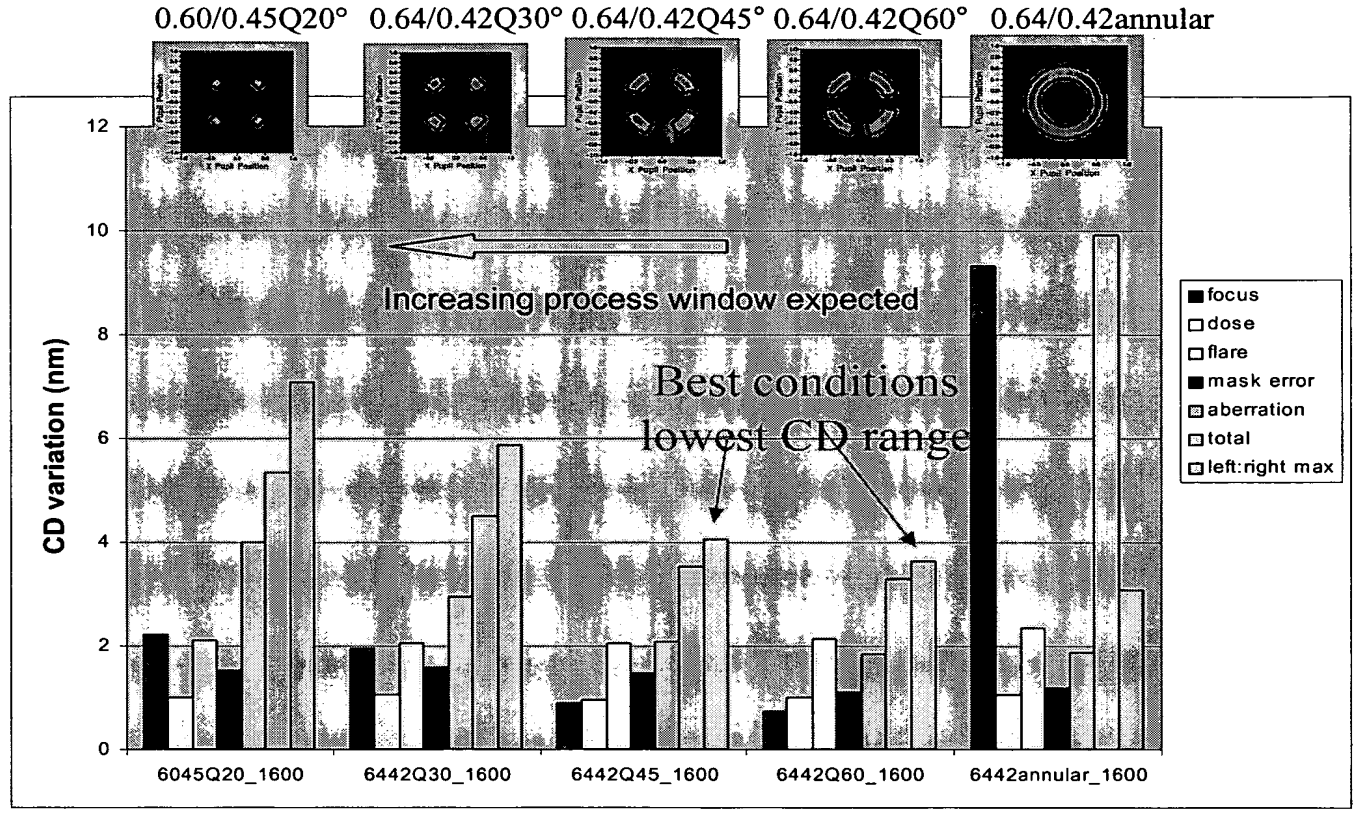

Lowest CD variation (best process!) is slightly off the diagonal
total CD variation
8.00-10.00
6.00-8.00
4.00-6.00
2.00-4.00
0.00-2.00
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Expect wider pole to improved CDU

FIG. 58



Selecting illuminator based on process window alone gives >50% more CD variation than if source visualization of CDU is included

FIG. 59